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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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where:

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1 presented to TSG for information;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

Introduction

Sustainable development is a long-term commitment in which all of us should take part. As part of sustainable development, people's fight against global warming should be without respite. Telecoms activities have a limited impact on environment: in 2007, the total footprint of the Information and Communication Technologies (ICT) sector was about 2% of the estimated total emissions from human activity and telecoms are only a part of ICT which represents no more than 25% of these 2%.

Nevertheless, most mobile network operators aim at reducing their greenhouse emissions, by several means such as limiting their networks' energy consumption.

In new generation Radio Access Networks such as LTE, Energy Savings Management(ESM) function takes place especially when mobile network operators want e.g. to reduce Tx power, switch off/on cell, etc. based on measurements made in the network having shown that there is no need to maintain active the full set of Network Elements (NEs) capabilities.

1 Scope

In the context of 3GPP Self-Organizing Networks (SON), this study investigates about Energy Savings Management in LTE / SAE networks, with the objective to contribute to the protection of our environment and the environment of future generations. One is forced to admit that, in addition, network energy consumption reduction will enable mobile network operators to save their OPEX.

The present document covers:

- Motivations of mobile network operators for the introduction of energy savings control mechanisms
- Analysis of possible mechanisms for Energy Savings Management via OAM
- Usage of existing IRPs to be used for the purpose of Energy Savings Management
- Identification of new IRP to be potentially defined
- Conclusions
    - Recommendations on Energy Savings Management
    - Identification of items for standardization as a result of this study

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 32.101 "Telecommunication management; Principles and high level requirements".

[3] 3GPP TS 32.102: " Telecommunication management; Architecture"

[4] 3GPP TR 36.902: " Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network use cases and solutions”

[5] 3GPP TS 25.104: "Base Station(BS) radio transmission and reception (FDD)"

[6] 3GPP TS 32.500: "Self-Organizing Networks (SON), Concepts and requirements"

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply:

A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply:

An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

BS Base Station
EMS Element Management System
EPC Evolved Packet Core
E-UTRAN Evolved UTRAN
ES Energy Savings
ESM Energy Savings Management
FFS For Further Specification
HSDPA High Speed Downlink Packet Access
ICT Information and Communication Technologies
IRP Integration Reference Point
LTE Long Term Evolution
MNO Mobile Network Operator
NE Network Element
NMS Network Management System
NRM Network Resource Model
OAM Operations, Administration, Maintenance
OPEX Operating Expenses
OSS Operation Support System
RAN Radio Access Network
SON Self-Organizing Networks
TRX Transceiver
UMTS Universal Mobile Telecommunications System
UTRAN Universal Terrestrial Radio Access Network
XML eXtensible Markup Language

4 Rationale for the Study on ESM

4.1 General

Protecting the environment and combating climate change are challenges for the human being. In the telecom environment, as energy prices increase, Network Operators are more and more taking care of their environmental responsibilities … and, of course, their energy bills.

Energy optimization in mobile networks can be envisioned as follows:

1. Firstly, it is desirable to optimize the number of sites, while maintaining coverage, capacity and quality of service. The permitted impact on coverage, capacity and quality of service is determined by operator's policy.

2. Secondly, effort should be put on finding out means to optimize energy efficiency of these sites and minimize energy consumption of equipment. The permitted impact on coverage, capacity and quality of service is determined by operator's policy.

3. Finally, research on renewable energy sources, (e.g. wind, solar energy), for mobile networks should have high priority.

In the context of LTE technology combined with SON functionalities, the objective of the present document is to identify mechanisms to optimize E-UTRAN equipment energy consumption (see bullet #2 above). OAM can play a central role in the optimization process, either directly (by locating the optimization function(s) within the management system) or indirectly (by providing relevant performance information to optimization functions elsewhere).

Radio Access Network (RAN) equipment is generally dimensioned to cope with peak hours. In a three-sector cell, with four TRXs per sector, this means that 12 TRXs are always active, whereas this is not always needed. By introducing advanced power management mechanisms, one (over four, in this example) TRX per sector could be put in stand-by mode during e.g. night hours. By only this kind of action, the potential energy savings across a network of thousands of eNodeBs could be high without any impact on service quality.

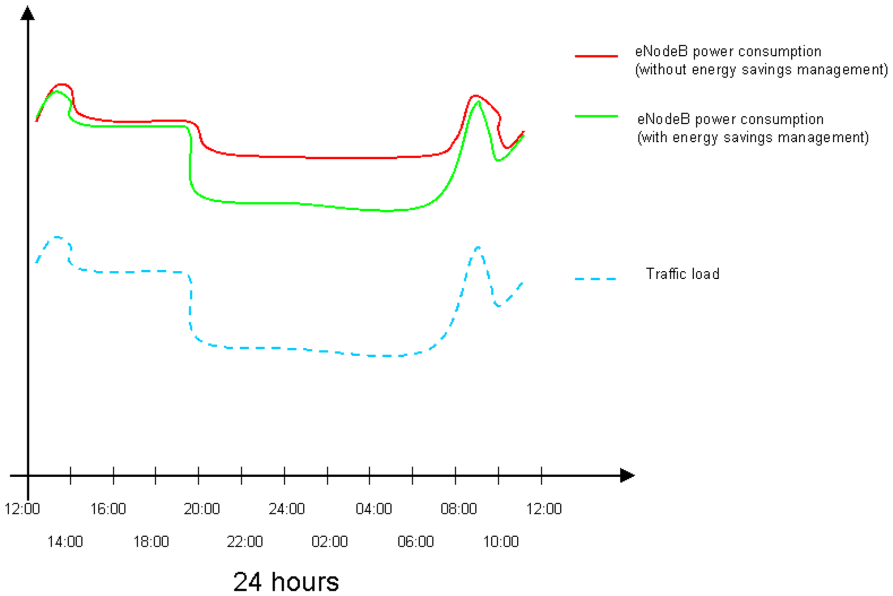

Figure 4.1 Traffic Load vs. Power Consumption

As for most SON functions, three architectures are candidate to offer energy savings functionalities:

- Distributed architecture, where NEs collect relevant information and trigger the appropriate self-optimising algorithms when needed, with no OA&M involvement;
- Centralized architecture, where OA&M collect relevant information from NEs, trigger the appropriate self-optimisation algorithm and decide on further actions on the NEs;
- Hybrid architecture, which is a mixture of the two aforementioned architectures.

The present document focuses on identifying mechanisms for ESM based on either centralized or hybrid approaches.

4.2 Study

A numerical study was performed in order to determine the potential energy saving that can be achieved by switching off BSs (sites) and/or spectrum (carriers) during off peak hours. Starting point was a UMTS/HSDPA network with a hexagonal layout of 48 sectorized sites, as shown in Figure 4.2.1

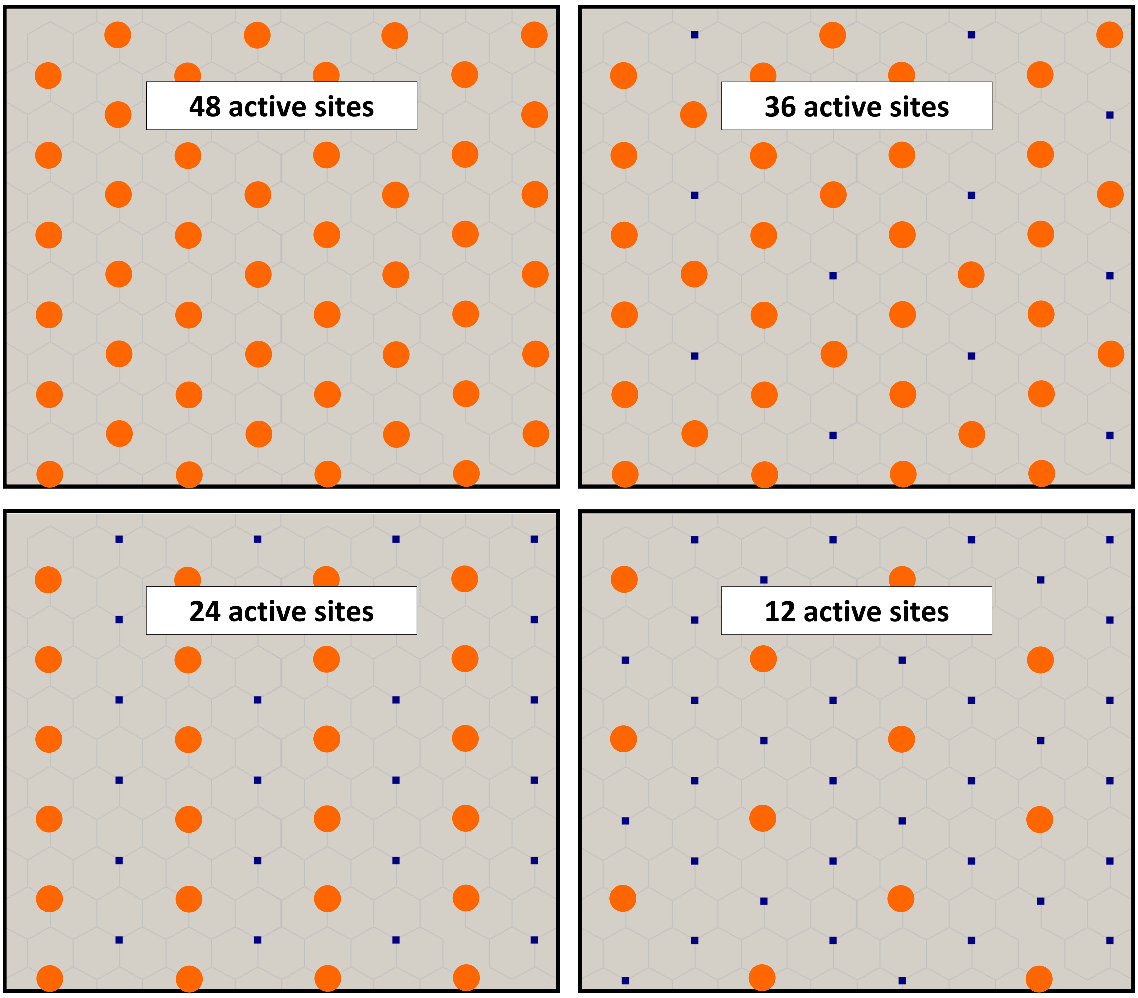

Figure 4.2.1 Hexagonal network layout with 48 sectorized sites. Four distinct configurations of a partial set of active sites are also depicted, comprising 48, 36, 24 or 12 active sites.

Besides the (complete) 48×3 layout, also a number of alternative $k \times 3$ network layouts were considered, with $k \in \{36,24,12\}$, where a specific subset of the original set of sites is switched off, while still preserving as much a regular layout of active sites as possible. All four considered cases are shown in Figure 4.2.1 . In the evaluations, the downtilt that is optimized for the full (48-site) configuration is maintained also in the 'reduced' configurations; hence no tilt adjustments are applied.

Each sector supports a maximum of four 5 MHz carriers (20 MHz). In the considered evaluations, the uniformly set number i of active carriers at an active site is 1, 2, 3 or 4.

In Annex A a detailed simulation procedure is explained for the derivation of the sites and carriers that can be turned off for a given traffic level (i.e. hour of the day) and quality objective defined as either average user or 10^{th} percentile cell edge throughput.

Let γ denote the activity factor i.e. the average transmit power of a sector. The applied energy consumption model is characterised by four parameters:

- P_{AC} is the energy consumption of a fully active air conditioning unit per site;
- $P_{CARRIER}$ is the energy consumption per fully active carrier (for the entire site); this captures all energy consumption not related to the air conditioner;

- α is the fraction of P_{AC} that is the minimum energy consumption of an air conditioning unit, regardless of the site's (in)activity or the sector's activity factor ;
- β is the fraction of $P_{CARRIER}$ that is the minimum energy consumption of a carrier, regardless of the carrier's (in)activity or the sector's activity factor.

Assume that P_{AC} = 1500 WATT and $P_{CARRIER}$ = 750 WATT, while different choices of α and β are considered, while the activity factor γ is readily obtained from the simulations (see Figure A.2 in Annex A). Considering only the scenario with the performance target on the 10th cell edge throughput percentile, for the case of $\alpha = \beta = 10\%$, Figure 4.2.2 shows for each hour of the day the energy consumption level if it is constantly deployed a configuration with 48 sites and 4 carriers, as well as the energy consumption level if in each hour of the day the most energy-efficient configuration is deployed (which still satisfies the imposed performance target). Additionally, for the latter case the figure indicates the optimal configuration S_{on}/C_{on}, written inside the light blue bars. For this scenario the average network-wide energy consumption level is about 4.01 MWATT for the default scenario and 2.72 MWATT for the energy-optimal scenario, which constitutes a savings of almost 28%.

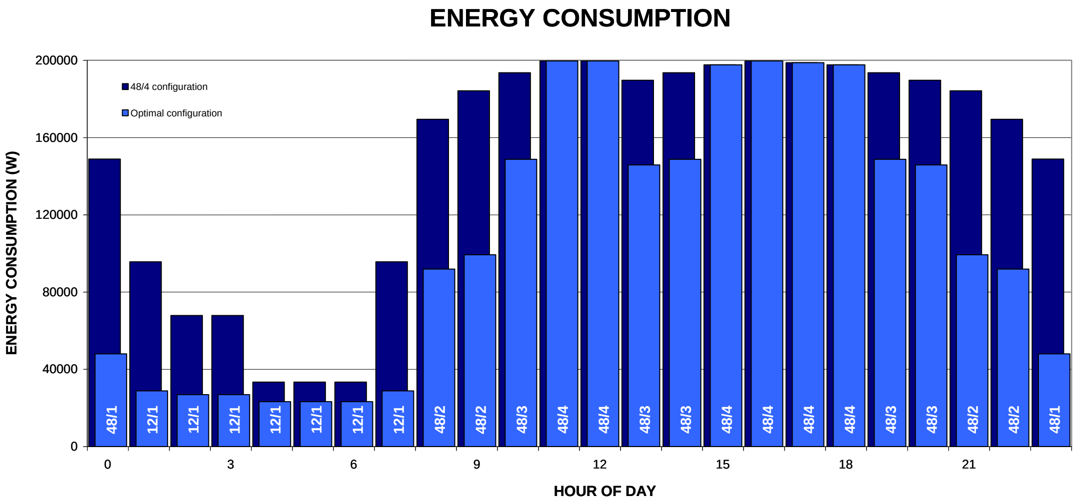

Figure 4.2.2 Default (dark blue) and optimal (light blue) energy consumption levels for different hours of the day

As a final exercise, it is assessed the sensitivity of the energy reduction factor with respect to the choices of α and β, as these parameters may take a range of settings in practical implementations. Figure 4.2.3 shows the results. Observe that the enrgy savings are largest for the case with a planning target on average user throughput. As could be expected, the energy savings are decreasing in both α and β. For the considered range of settings the savings vary between about 18% and 38%.

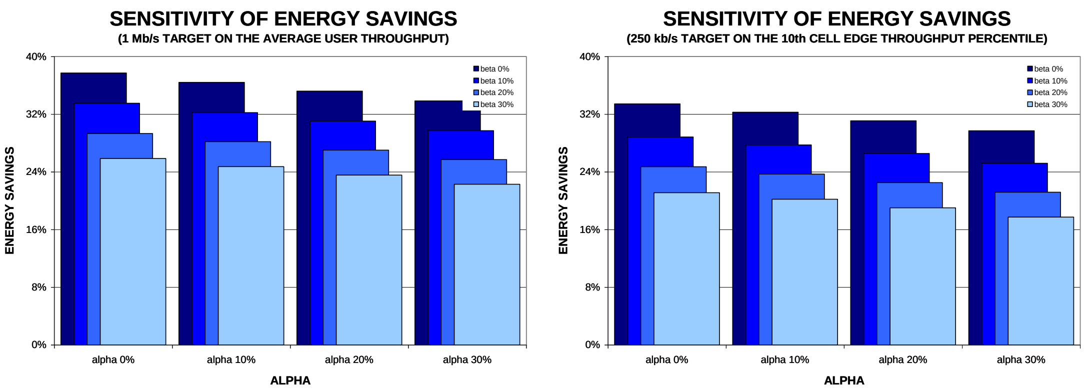

Figure 4.2.3 Sensitivy assessment of the energy savings w.r.t. energy model parameters α and β.

Considering an HSDPA network, distinct planning targets and a typical variation of the daily traffic load, it is shown that appropriately switching off sites and/or carriers can result in energy savings of up to 38%. For the considered range of settings for the power consumption of the inactive sites/carriers the energy savings vary between about 18% and 38%.

NOTE: For practical deployments and considering e.g. non-linear dependency of the power consumption with respect to traffic activity, irregular site deployment, non-homogenous traffic spatial distribution, specific terrain or man-made obstacles, etc. the achievable energy saving potential may deviate from the range reported in this analysis. Especially, if there are constraints for switching off particular sites/carriers in the network the achievable gains will be smaller than those reported in this analysis.

Editor's note : There is a variance of the temperature during the day and this may affect the potential of the energy savings and the results of the simulation. In the above study the assumptionof a constant temperature throughout the day was made.

5 Concepts and Background

5.1 Energy Savings Management (ESM) concept

ESM addresses both Macro and Home eNodeBs.

Two energy saving states can be conceptually identified for a network element:

- **notParticipatingInEnergySaving** state: state in which no energy saving functions is in progress.

- **energySaving** state: state in which the network element is powered off or restricted in physical resource usage in other ways.

Editor's Note3: "Powerd off" The radio part of the NE is OFF. The Control part of the NE is ON. The radio part of the NE can be turned ON if needed

Based on the above energy saving states, a full energy saving solution includes two elementary procedures:

- Energy saving activation: The procedure to switch off eNB/cell or restrict the usage of corresponding physical resources in order to satisfy energy saving purpose. As a result, a specific network element enters in the energy saving state.

- - Energy saving deactivation: The procedure to switch on eNB/cell or resume the usage of corresponding physical resources in order to satisfy the increasing service/QoS requests. As a result, a specific network element transitions from energySaving to notParticipatingInEnergySaving state.

For some use cases of energy saving management, a network element may additionally transition into the compensatingForEnergySaving state, defined as follows:

- **compensatingForEnergySaving** state: state in which the network element is remaining powered on, and taking over the coverage areas of geographically closed network element in energySaving state.

Correspondingly, an energy saving solution may also include the following procedures:

- Energy saving compensation activation: the procedure to change a network element's configuration to remain powered on for compensating energy saving activation on other network elements, e.g., by increasing its coverage area. As a result, the network element enters compensatingForEnergySaving state.

- Energy saving compensation de-activation: the procedure to transition from compensatingForEnergySaving state to notParticipatingInEnergySaving state, e.g., by decreasing the previously increased coverage area..

5.1.1 Configuration Management

Based on traffic load measurements / service usage data, OAM can decide to take appropriate actions on the NEs for the sake of energy savings. Examples of such actions include:

Switch cell OFF / ON

Switch carrier, IFs OFF / ON

Reduce / Increase TRX power

Switch Home eNodeB OFF / ON

Other: FFS.

For each of the aforementioned possible actions, the potential impact on coverage, capacity and service quality should be assessed carefully. For example, switching off a cell should be done only when neighbour cells can ensure coverage and pre-defined level of capacity.

Editor's note2 : The following paragraph is FFS.

Furthermore, before initiating Energy Savings Management actions, OAM should compare current traffic load with measurement data collected during previous days at same time. For example, a football stadium might have few or no traffic every day, except during football matches with audience. This implies that the Energy Savings Management function should be able to reduce power consumption for e.g. all week days, except those when a football match with audience is played. Therefore the ability should be given to control Energy Saving Management actions either calendar-based or trigger based.

5.1.2 Regulatory Requirements

ESM actions should not harm any regulatory and legal requirements.

5.1.3 Logical Function Blocs

VOID

6 Business Level Requirements

REQ-ES_MM-CON-1 Operator shall be able to manage the energy savings function.

REQ-ES_MM-CON-2 Energy savings shall be performed with minimal human intervention.

REQ-ES_MM-CON-3 The acceptable impacts on services shall be determined based on operator's policy.

REQ-ES_MM-CON-4 Management of Energy Savings function shall reuse existing standardized solutions where beneficial.

REQ-ES_MM-CON-5 The following scenarios shall be considered in energy savings management.

1. ENB Overlaid
2. Carrier Frequency Restricted

6.1 Actor roles

VOID

6.2 Telecommunications resources

VOID

6.3 High-level use cases

ENB Overlaid

In order to assure the service connectivity and make no side effect on the service (there is a possible case that a UE may power on in the area of an eNB in ES), only the eNB overlaid by other eNBs (i.e., the area served by the eNB also covered by other eNBs) can enter into ES.

In this scenario, legacy systems, e.g. 2G/3G provide radio coverage together with E-UTRAN. Another case similar with this is that an area covered by different frequencies in E-UTRAN, i.e. inter-frequency case.

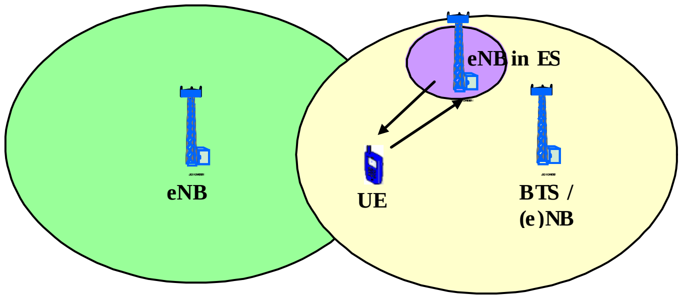

Figure 6.3 ENB Overlaid Scenario

According to the definition of base station classes in [5] section 4.2, base stations can be categorized by Macro Cell (Wide Area Base Station), Micro Cell (Medium Range Base Station) , Pico Cell (Local Area Base Station) and Femto Cell (characterized by Home Base Station). This category of base station can be applied to enhance the scenarios of inter-frequency eNB overlaid.

UC1: Inter-Frequency E-UTRAN eNB/Cell Coverage

In this scenario, two E-UTRAN cells (Cell A, Cell B) with separate frequency bands cover the same geographical area. Cell B has a smaller size (Pico Cell or Micro Cell) than Cell A (Macro Cell) and is covered totally by Cell A. Generally, Cell A is deployed to provide continuous coverage of the area, while Cell B increases the capacity of the special sub-areas, such as hot spots. The energy saving procedure in the coverage of Cell B (ES area) may be triggered in case that light traffic in Cell B is detected. Cell B deactivation of energy saving may also be triggered when the traffic of ES area (measured by Cell A) resumes to a high level.

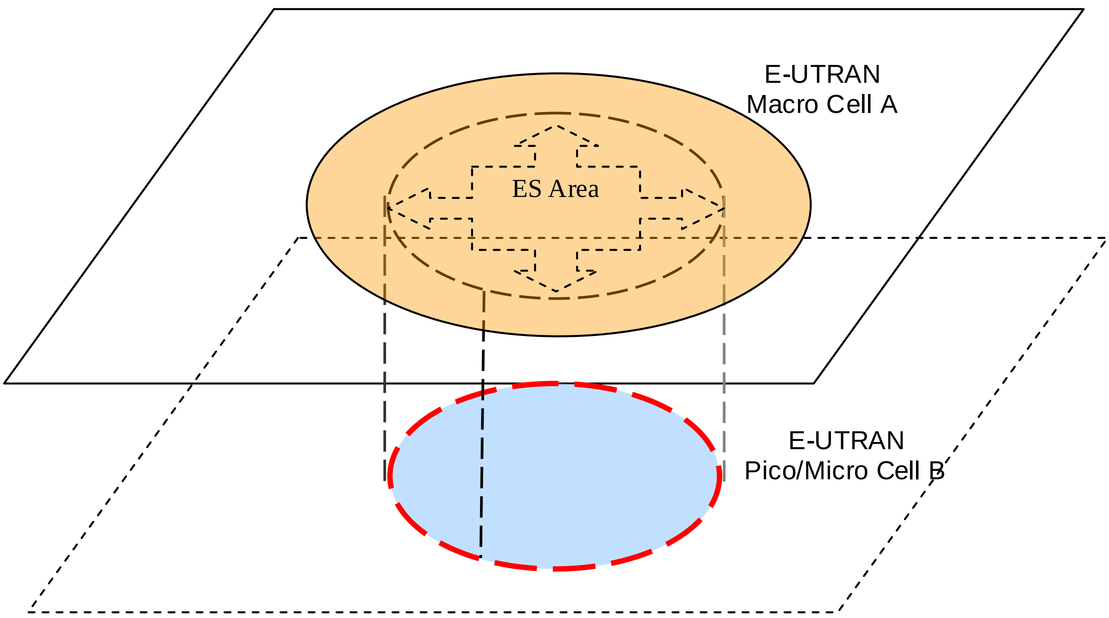

Figure 6.3.1 Inter-Frequency E-UTRAN Cell Coverage

The inter-frequency E-UTRAN cell coverage use case also has a variation of hybrid deployment of Macro Cell and Femto Cell, which means different cell classes (Macro and Femto) cover the same geography area.

UC1a: Hybrid E-UTRAN Macro Cell and Femto Cell Coverage

In this scenario, two E-UTRAN cells (Cell A, Cell B) with different cell types cover the same geographical area. Cell B (Femto Cell) is covered totally by Cell A (Macro Cell). Generally, Cell A is deployed by eNB to provide continuous coverage of the area, while Cell B is deployed by Home eNB to increase the capacity of the special sub-areas, such as home or business mall or office. The energy saving procedure in the coverage of Cell B (ES area) may be triggered in case that light traffic or no traffic in Cell B is detected. Cell B deactivation of energy saving may also be triggered when the traffic of ES area resumes to a high level. Home eNB which deploys the femto cell can be totally switched off during the ES procedure.

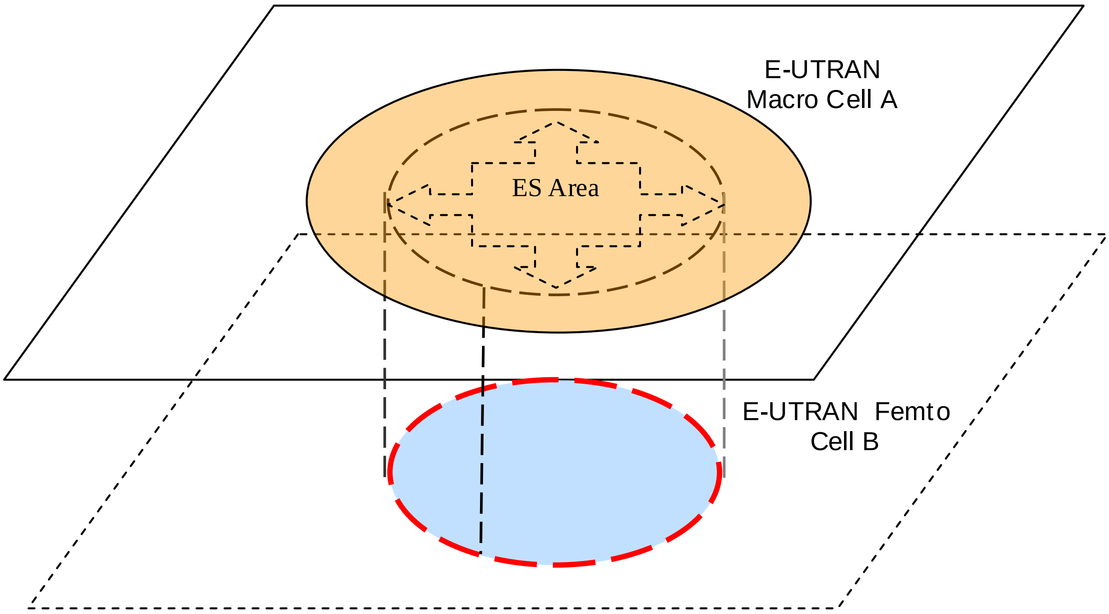

Figure 6.3.2 Hybrid E-UTRAN Macro Cell and Femto Cell Coverage

UC2: Inter-RAT Cell Coverage

In this scenario, E-UTRAN Cell B is totally covered by inter-RAT Cell A (such as legacy system UMTS or GSM). Cell A is deployed to provide basic coverage of the voice or medium/low-speed data services in the area, while Cell B enhances the capability of the area to support high-speed data or multi-media services. The energy saving procedure in the coverage of Cell B (ES area) may be triggered in case that no high-speed data or multi-media traffic in Cell B is detected. Cell B deactivation of energy saving may be triggered when the high-speed data or multi-media service request in ES area is restarted again.

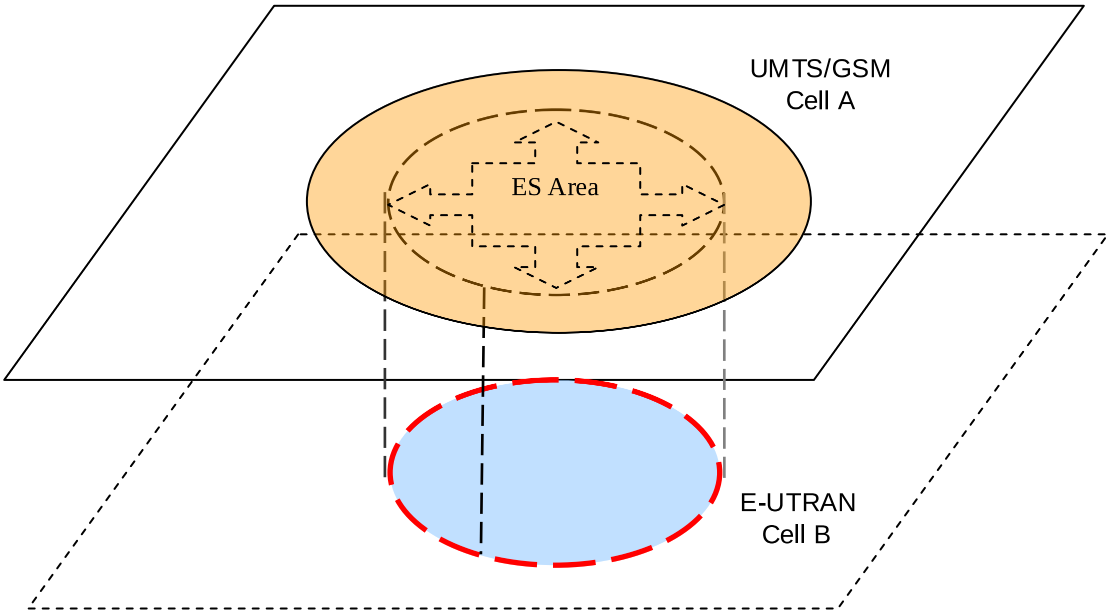

Figure 6.3.3 Inter-RAT Cell Coverage

ENB Restricted

In the scenario of eNB restricted, the overlaid eNB can be totally switched off during the spare time of public area, e.g., during the night of mall/office.

Carrier Frequency Restricted

In the scenario of carrier frequency restricted, eNB restricts the use of some carriers and keeps a primary carrier. This is a common case where eNB could operate on multiple carrier frequencies.

Capacity-limited Network

Capacity-limited, homogeneous networks (e.g., UMTS networks in an urban environment) are normally dimensioned to cope with peak time traffic demand and can hence be under-utilized in off-peak times, e.g., at certain hours of the night, when the overall load as well as the load distribution onto the different cells may differ significantly from peak times.

For energy-saving management, the objective is therefore to adapt the network to these changing conditions. One approach is to concentrate the load into a few selected cells that remain active during low traffic demand periods with increased coverage area and to de-activate the remaining less loaded cells as described in more detail in [7].

We assume that the coverage area of a cell can be configured dynamically and that a peak-time situation would be based on smaller coverage areas per cell than the possible maximum area. In that case some base stations would be enabled to adjust their transmission power and other configuration parameters for their cells at off-peak times in order to provide coverage for other neighboring cells – which could then be switched off, after handing currently associated UEs over to remaining neighboring cells. Turning off cells and modifying radio parameters for increasing coverage for other cells can lead to a different cell and frequency layout, which should be addressed by interference control, e.g., through OAM-driven configuration or SON functions. Depending on the specific scenarios, switching off cells could ultimately lead to switching off all radio-transmission-related functions at a site, which would lead to reduced energy consumption and could implicitly lead to even further energy-saving, e.g., when air condition systems at a site adapt to the reduced cooling requirements – which is not considered here in detail.

The energy saving management in the scenario would ideally lead to situation for an off-peak time as depicted in figure 6.3.4 – where one base station would remain powered one (depicted as ES-Compensate), taking over the coverage areas of geographically close base stations in ESaving (energy saving) state that may, e.g., be powered off.

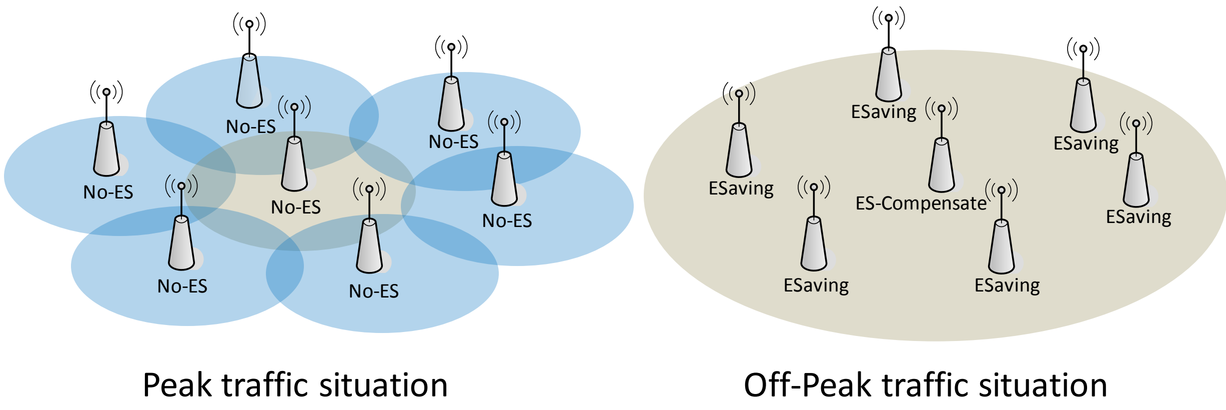

Figure 6.3.4 Different network arrangements corresponding to capacity demand variation for energy saving purposes

As depicted in figure 6.3.4, a certain part of a network, e.g., base stations in a geographical area, can be in two different situations:

1. *Peak traffic situation*: no particular energy saving is on-going, and network elements are in *No-ES state*.
2. *Off-peak Traffic situation*: energy saving is on-going, and some network elements may be in *ESaving mode*, while others are in *ES-Compensate mode*.

Peak-traffic situation and *off-peak-traffic situation* refer to the disposition of a network. For this use case, the following different states from section 5.1 are applicable to individual network elements:

1. *No-ES (notParticipatinginEnergySaving) state*: the default state in *peak-traffic situation*, with no specific energy saving in progress.
2. *ESaving state*: in an *off-peak-traffic situation*, the network element is powered-off or restricted in resource usage in other ways.
3. *ES-Compensate (compensatingForEnergySavings) state*: in an *off-peak traffic situation*, a network element is remaining powered on, taking over the coverage areas of geographically close base station in *ESaving state*.

These states are entered and left using the procedures defined in section 5.1, i.e., *energy saving activation*, *energy saving de-activation*, *energy saving compensation activation*, and *energy saving compensation de-activation*.

It should be noted that the concrete actions for transferring a network element into an energy-saving state (depicted as "ESaving" in figure 6.3.4) depend on the specific scenario and capabilities of the network element.

Reaching *off-peak-situation* with the respective state changes on network elements is a process that affects an operator-defined part of the network. For this use case, the energy saving function requires an algorithm to select

- a) the network elements to stay in *No-ES state* and those network elements to leave this state; and
- b) from the set of network elements leaving *No-ES state*, the network elements to enter *ESaving state* and those elements to enter *ES-Compensate state*.

Such an algorithm could use load parameters, geographic information etc., and should provide a smooth transition between peak hours and off-peak hours, taking into account the achievable energy saving gains and the impact on the network performance.

Moreover, an algorithm for the process of reverting from an *off-peak situation* with maximum or partial energy saving is needed that supports re-acting to increasing capacity demand, e.g., by selecting currently *ESaving* base stations for energy saving de-activation as required. In addition to that, it should also be possible to terminate the complete energy saving function unconditionally.

Whereas energy saving (de-)activation, energy saving compensation (de-)activation (as described above) refer to configuration changes performed on individual network elements, these algorithms are processes that typically involve more than one network element and – depending on the chosen approach – also network management systems. Here, we assume that for a part of the network (as a system) energy saving management would either be enabled, i.e., *energy-*

saving (de-)activation and *energy saving compensation (de)-activation* is initiated on network elements according to the performed algorithms) or energy saving management would be disabled, i.e., these algorithms are not executed.

The operation of the energy saving algorithms suggest the adoption of a coordinated process in the context of [8] since the decision to initiate energy saving activation for certain cells is requiring information beyond a single network element, e.g., load information from neighbors.

From a network management perspective, there may be different ways to implement the processes of enabling and disabling ESM:

1. Centralized energy saving management:

For centralized ESM, OAM decides on enabling / disabling ESM in the network. When ESM is enabled, OAM, applying its energy saving algorithm, determines, based on load and other network utilization information and based on knowledge about geographic positions and coverage areas of base stations, which base stations are to enter *ESaving state*, *ES-Compensate state*, or *No-ES state*.

When ESM is disabled, OAM initiates energy saving de-activation on network elements, i.e., by transferring them into *No-ES state*.

In summary, for centralized ESM, OAM enabled / disables ESM, and – when ESM is enabled – executes energy saving algorithms and configures network elements to either *ESaving state*, *ES-Compensate state*, or *No-ES state*.

2. Distributed energy saving management:

For distributed ESM, OAM decides on enabling / disabling ESM in the network. When ESM is enabled, network elements execute the energy saving algorithm in a distributed manner to determine cells to enter *ESaving state*, *ES-Compensate state*, or *No-ES state* – depending on knowledge of current load information of neighboring base stations.

When OAM disables ESM, network elements perform energy saving de-activation, i.e., they return to *No-ES state*.

The distributed approach requires neighboring base stations to exchange load information on regular intervals. Consequently, the energy saving algorithm is performed based on coordination a more local scope compared to the centralized approach.

In summary, for distributed ESM, OAM enables / disables ESM, but the energy saving algorithm is executed in a distributed fashion by network elements that decide which base station should enter which state (*No-ES*, *ESaving*, *ES-Compensate*).

3. Hybrid energy saving management:

For hybrid ESM, OAM decides on enabling / disabling ESM in the network, and the energy saving algorithm may be executed on both OAM and network elements or solely on network elements.

When the OAM enables ESM, network elements execute the energy saving algorithm in coordination with OAM to determine when which network elements should enter *ESaving state*, *ES-Compensate state*, or *No-ES state* – e.g., depending on knowledge of current load information of neighboring base stations. In addition, OAM may perform an additional energy saving algorithm based on global load constraints to initiate entering *ESaving state*, *ES-Compensate state*, or *No-ES state* on certain base stations explicitly or to provide hinds as input to the energy algorithms executed on each individual emenent. For example, OAM could perform load measurements considering a larger set of network elements and may thus be enabled to come to better-informed conclusions about energy saving in a certain region, which could result into certain policies that OAM provides to network elements to enhance the ESM process. In order to avoid or resolve conflicts in such scenarios, prioritization of decisions or conflict resolution may be required.

When the OAM disables ESM, network elements perform energy saving de-activation, i.e., they return to *No-ES state*. In addition, OAM may also initiate *energy saving de-activation* on specific network elements.

The hybrid approach requires neighboring base stations to exchange load information and push or pull load information towards OAM on regular intervals. Consequently, the energy saving algorithm is performed based on a coordination on both local and global scope, which could scale accordingly.

In summary, for hybrid ESM, OAM enables / disables ESM, but the energy saving algorithm is executed in distributed or coordinated fashion by either network elements solely or in combination with OAM.

It should be noted that the notion of enabling / disabling ESM and the different network element states are used here for better illustrating the use case and that they do not imply specification-level requirements.

eNB Time Scheduled Switch Off/On

In some special deployment areas the variation of eNB service traffic is regular Therefore, the eNB can be simply switched off during the time scheduled interval with zero traffic (e.g. 10:pm to 06:00 am of the next day) and then turned on after that period per day.

7 Specification Level Requirements

7.1 General

VOID

7.2 Actor roles

VOID

7.3 Telecommunications resources

VOID

7.4 Use cases

7.4.1 Use case eNodeB Overlaid

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Switch OFF the radio part of the (Home) (e)NodeB(s) for energy saving purposes.	
Actors and Roles (*)	FFS	
Telecom resources	The (Home) eNodeB(s) including its OSS.	
Assumptions	Energy Savings management mode is activated for the (Home) eNodeB(s), based on operator's policy. The subject (Home) eNodeB(s) is overlaid by one (or more) other (Home) (e)NodeB(s).	
Pre conditions	The (Home) eNodeB(s) is switched on. The (Home) eNodeB(s) is not in a faulty state. The Energy Savings Management is activated	
Begins when	The energy savings management process is triggered automatically based on network performance measurements / service usage data collection and analysis.	
Step 1 (*) (M|O)	[SC1] Compliance of switching off the eNB radio part is checked and if confirmed, the radio part is switched off.	
Ends when (*)	The operator policy does not allow switching off or the Energy Savings Management is deactivated or when an exception occurs.	
Exceptions	FFS.	
Post Conditions	The radio part of the (Home) eNodeB(s) is OFF. The Control part of the (Home) eNodeB(s) is ON. The radio part of the (Home) eNodeB(s) can be turned ON if needed.	
Traceability (*)		

7.4.2 Use case capacity-limited network

Based on the high-level description in section 6.3, different use cases for energy saving management in capacity-limited networks are provided: centralized ESM (enabling and disabling energy saving) and hybrid ESM (enabling and disabling energy saving). It should be noted that the notion of enabling / disabling ESM and the different network element states are used here for better illustrating the use cases and that they do not imply specification-level requirements.

7.4.2.1 Centralized ESM

7.4.2.1.1 Enabling energy saving

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Enable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	The network operator has decided to enable energy saving for a selected part of the network (network elements, e.g., base stations).	
Pre conditions	The base station topology for a selected area allows for transferring some network elements into *ESaving state* while maintaining coverage by transferring some other base stations into *ES-Compensatestate.* Network elements (e.g. eNodeBs) are not in a faulty state.	
Begins when	OAM decides to enable energy saving for a selected part of the network.	
Step 1 (*) (M)	OAM based on load and other network utilization information and based on knowledge about geographic positions and coverage areas of base stations, decides which network elements are to enter *ESaving state*, *ES-Compensate state*, or *No-ES state.*	
Step 2 (*) (M)	On those network elements that will be transferred to *ESaving state,* OAM initiates energy-saving activation.	
Step 3 (*) (M)	On those network elements that will be transferred to *ES-Compensate state,* OAM initiates energy-saving compensation.	
Ends when (*)	The selected network elements are in *ESaving state*, and other selected network elements are in *ES-Compensate state*.	
Exceptions	FFS	
Post Conditions	Energy-saving activation has been performed on some selected network elements. Other selected network elements are in *ES-Compensate* state. The network coverage for the selected area is maintained. The overall energy consumption for the corresponding part of the network is reduced.	
Traceability (*)	REQ_ESM_CON_004, REQ_ESM_CON_005	

7.4.2.1.2 Disabling energy-saving

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Disable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	In a part of the network some network elements (e.g., base stations) are in *ESaving state* and other network elements are in *ES-Compensate state*. The operator has decided to disable energy saving for that part of the network.	
Pre conditions	The affected network elements are in *ESaving state or in ES-Compensate state.* Network elements (base stations) are not in a faulty state.	
Begins when	OAM decides to disable energy-saving for a selected part of the network.	
Step 1 (*) (M)	OAM initiates energy saving de-activation on every network element in the corresponding part of the network.	
Ends when (*)	Energy-saving de-activation has been initiated on all network elements in the corresponding part of the network.	
Exceptions	FFS.	
Post Conditions	All network elements in the corresponding part of the network are in *No-ES (notParticipatinginEnergySaving) state*.	
Traceability (*)		

7.4.2.2 Distributed ESM

7.4.2.2.1 Enabling energy saving

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Enable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	The network operator has decided to enable energy saving for a selected part of the network (network elements, e.g., base stations).	
Pre conditions	The base station topology for a selected area allows for transferring some network elements into *ESaving state* while maintaining coverage by transferring some other network elements into *ES-Compensate state.* Network elements (e.g. eNodeBs) are not in a faulty state.	
Begins when	OAM decides to enable energy saving for a selected part of the network.	
Step 1 (*) (M)	OAM enables energy saving for a selected part of the network.	
Step 2 (*) (O)	OAM provides policies to the network elements in order to support the execution of the energy saving algorithms on these elements.	
Step 3 (*) (M)	Network elements execute the energy saving algorithm to determine when which network elements should enter *ESaving state*, *ES-Compensate state*, or *No-ES state* – e.g., depending on knowledge of current load information of neighboring base stations	
Step 4 (*) (M)	Those network elements that have been selected to be transferred to *ESaving state,* perform energy-saving activation.	
Step 5 (*) (M)	Those network elements that have been selected to be transferred to *ES-Compensate state,* initiate energy-saving compensation.	
Ends when (*)	The selected base stations are in *ESaving state*, and other selected base stations are in *ES-Compensate state*.	
Exceptions	FFS.	
Post Conditions	Energy-saving activation has been performed on some selected network elements. Other selected network elements are in *ES-Compensate* state. The network coverage for the selected area is maintained. The overall energy consumption for the corresponding part of the network is reduced.	
Traceability (*)	REQ_ESM_CON_005	

7.4.2.2.2 Disabling energy saving

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Disable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	In a part of the network some network elements (e.g., base stations) are in *ESaving state* and other network elements are in *ES-Compensate state*. The operator has decided to disable energy saving for that part of the network.	
Pre conditions	The affected network elements are in *ESaving state or in ES-Compensate state.* Network elements (base stations) are not in a faulty state.	
Begins when	OAM decides to disable energy-saving for a selected part of the network.	
Step 1 (*) (M)	OAM disables energy-saving for a selected part of the network.	
Step 2 (*) (M)	Network elements (e.g. base stations) in the selected part of the network de-activate energy saving.	
Ends when (*)	Energy-saving de-activation has been initiated on all network elements in the corresponding part of the network.	
Exceptions	FFS.	
Post Conditions	All network elements in the corresponding part of the network are in *No-ES (notParticipatinginEnergySaving) state*.	
Traceability (*)	REQ_ESM_CON_006	

7.4.2.3 Hybrid ESM

7.4.2.3.1 Enabling energy saving

Use Case Stage	**Evolution / Specification**	**<<Uses>> Related use**
Goal (*)	Enable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	The network operator has decided to enable energy saving for a selected part of the network (network elements, e.g., base stations).	
Pre conditions	The base station topology for a selected area allows for transferring some network elements into *ESaving state* while maintaining coverage by transferring some other network elements into *ES-Compensate state.* Network elements (e.g. eNodeBs) are not in a faulty state.	
Begins when	OAM decides to enable energy saving for a selected part of the network.	
Step 1 (*) (M)	OAM enables energy saving for a selected part of the network.	
Step 2 (*) (O)	OAM provides policies to the network elements in order to support the execution of the energy saving algorithms on these elements.	
Step 3 (*) (M)	Network elements execute the energy saving algorithm to determine when which network elements should enter *ESaving state*, *ES-Compensate state*, or *No-ES state* – e.g., depending on knowledge of current load information of neighboring base stations	
Step 4 (*) (M)	Those network elements that have been selected to be transferred to *ESaving state,* perform energy-saving activation.	
Step 5 (*) (M)	Those network elements that have been selected to be transferred to *ES-Compensate state,* initiate energy-saving compensation.	
Step 6 (*) (O)	In addition, OAM performs an additional energy saving algorithm based on global load constraints to initiate entering *ESaving state*, *ES-Compensate state*, or *No-ES state* on certain network elements explicitly or to provide hints as input to the energy algorithms executed on each individual emenent.	
Ends when (*)	The selected base stations are in *ESaving state*, and other selected base stations are in *ES-Compensate state*.	
Exceptions	FFS.	
Post Conditions	Energy-saving activation has been performed on some selected network elements. Other selected network elements are in *ES-Compensate* state. The network coverage for the selected area is maintained. The overall energy consumption for the corresponding part of the network is reduced.	
Traceability (*)	REQ_ESM_CON_005, REQ_ESM_CON_007	

7.4.2.3.2 Disabling energy saving

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Disable energy saving for a selected part of the network (network elements, e.g., base stations)	
Actors and Roles (*)	IRPManager as user	
Telecom resources	Network elements and their OSS.	
Assumptions	In a part of the network some network elements (e.g., base stations) are in *ESaving state* and other network elements are in *ES-Compensate state*. The operator has decided to disable energy saving for that part of the network.	
Pre conditions	The affected network elements are in *ESaving state or in ES-Compensate state.* Network elements (base stations) are not in a faulty state.	
Begins when	OAM decides to disable energy-saving for a selected part of the network.	
Step 1 (*) (M)	OAM disables energy-saving for a selected part of the network.	
Step 2 (*) (M)	Network elements (e.g. base stations) in the selected part of the network de-activate energy saving.	
Step 3 (*) (O)	In addition, OAM may also initiate energy saving de-activation on specific network elements.	
Ends when (*)	Energy-saving de-activation has been initiated on all network elements in the corresponding part of the network.	
Exceptions	FFS.	
Post Conditions	All network elements in the corresponding part of the network are in *No-ES (notParticipatinginEnergySaving) state*.	
Traceability (*)	REQ_ESM_CON_006	

7.4.3 Use Case eNodeB Time Scheduled Energy Saving Activation/Deactivation

Use Case Stage	Evolution / Specification	<<Uses>> Related use
Goal (*)	Energy Saving activation/deactivation in an eNodeB based on time schedule	
Actors and Roles (*)	IRPManager as user	
Telecom resources	The eNodeB including its OSS.	
Assumptions	Energy Savings Management Function is present. The eNodeB is deployed in an area where time scheduled intervals with zero traffic load are predictable.(on per day, week or month basis). There is no ES policy is in effect. Note: ES policy coordination or conflict resolution is FFS.	
Pre conditions	The eNodeB is switched on and carrying traffic. The eNodeB is not in a faulty state. The Energy Savings Management Function is on The operator policy allows energy saving activation/deactivation in an eNodeB based on time schedule	
Begins when	Alternative 1: IRPManager informs IPRAgent/Energy Saving Management Function a time scheduled energy saving policy for the eNodeB. The policy is to switch off the eNB during time scheduled intervals with zero traffic load. IRPManager provides the time scheduled intervals. Alternative 2: IRPManager/Energy Saving Management Function holds the time scheduled energy saving policy.	
Steps	Alternative 1: 1. Energy saving activation is performed when the beginning of a time scheduled interval is reached. As a result, the eNB is switched off. 2. Energy saving deactivation is performed when the end of the time scheduled interval is reached. As a result, the eNB is switched on. 3. Go back to step 1. Alternative 2: 1. IRPManager sends request at beginning of a time schedule interval to IRPAgent to switch off the eNB. 2. IRPManager sends request at end of the time schedule interval to IRPAgent to switch on the eNB. 3. Go back to step 1	
Ends when (*)	Alternative 1: IRPManager informs IRPAgent and Energy Saving Management Function to stop instructing eNodeB to be switched off based on time schedule or Alternative 1 and 2: when all the time scheduled interval with zero traffic load expire.	
Exceptions	FFS.	
Post Conditions	Energy saving activation/deactivation based on time schedule is disabled in the eNodeB	
Traceability (*)		

7.5 Requirements

REQ_ESM_CON_001 The IRPManager shall be able to monitor how the network and the user service quality are influenced by energy savings function.

REQ_ESM_CON_002 The IRPManager shall be able to configure energy saving function related parameters.

REQ_ESM_CON_003 The IRPManager shall be able to monitor the performance of the energy savings function.

REQ_ESM_CON_004 The IRPManager shall be able to initiate energy saving compensation on network elements. This requirement applies for the use case capacity limited network, for other use cases it is FFS.

REQ_ESM_CON_005 The IRPManager shall be able to enable energy saving for a selected part of the network.

REQ_ESM_CON_006 The IRPManager shall be able to disable energy saving for a selected part of the network.

REQ_ESM_CON_007 The IRPManager shall be able to provide policies to network elements to support the execution of energy saving algorithms on these elements

REQ_ESM_CON_008 The IRPAgent shall support a capability allowing the IRPManager to initiate energy saving activation procedure to one or multiple network elements.

REQ_ESM_CON_009 The IRPAgent shall support a capability allowing the IRPManager to initiate energy saving deactivation procedure to one or multiple network elements.

REQ_ESM_CON_010 When a NE is "switched off" due to Energy savings purposes the IRPAgents shall not consider a "switched off" NE as a fault, and no alarms shall be raised to the IRPManager for any condition that is a consequence of a "switched off" NE.

REQ_ESM_CON_0011 The IRPAgent shall support a capability allowing the IRPManager to retrieve energy consumption information for each of its managed NEs.

REQ_ESM_CON_0012 The IRPAgent should support a capability allowing the IRPManager to configure for each of its managed NEs the period of time during which energy consumption information will be provided.

REQ_ESM_CON_0013 The IRP Agent shall be able to allow the IRPManager to "whitelist" a list of cells to prevent them from switching off.

REQ_ESM_CON_0014 The IRPAgent shall allow the IRPManager to query for all switched off cells in the network under its domain.

REQ_ESM_CON_0015 The IRPAgent shall support a capability allowing the IRPManager to initiate energy saving activation/deactivation procedure at the cell level (one or more cells across multiple eNBs).

REQ_ESM_CON_0016 The IRPAgent shall support a capability to notify the IRPManager when a cell goes into or out of energy saving mode (switched off/, switched on, switched to dormant etc).

REQ_ESM_CON_0017 The IRPAgent shall notify the IRPManager when a cell fails to re-start as a result of a switch-on due to energy saving.

7.5.1 Service Quality Measurements Collection

REQ_ESMeNBOSQMC_FUN_1 The IRPAgent shall provide to the IRPManager service quality measurements performed in order to identify potential service impacts due to the ESM process activation.

8 Functions and Architecture

8.1 Energy Savings Management Definition

Energy Savings Management (ESM) is a function which is responsible for optimizing the resource utilization of the whole or part of the network to actual needs for power saving purposes. ESM will collect and evaluate service usage related information from the network, and initiate appropriate actions to adjust the network configuration to service requirements, according to the service provider's policy.

The Energy Savings Management can be:

Centralised : In such solutions the appropriate energy saving actions are initiated, by the Energy Savings algorithms, which resides in the OAM System.

Distributed: In such solutions the appropriate energy saving actions are initiated, by the Energy Savings algorithms, which resides at the NE level.

The key feature to distinguish centralised and distributed ESM solutions is what entity or role makes decision to initiate energy saving actions, OAM system or NE(for example, eNB). The decision is made by OAM system in a centralised solution while it is made by NE itself in a distributed solution (based on NE's local trigger condition judgement). The table below summarizes the differences between the two categories of ESM solutions, featured by three comparison features.

Comparison Feature	Centralised ESM solution	Distributed ESM solution
Energy saving related measurements	OAM system	NE
Decision making to trigger ES actions	OAM system	NE
Energy saving action execution	NE	NE

However, for a hybrid ESM solution, the management scenario needs to combine both parties (OAM system and NE) of decision-making to trigger actual energy saving actions. Information related to the energy saving decision making shall be exchanged between OAM system and NE. Like for the definition of hybrid SON in TS 32.500 [6], "hybrid" means that one part of energy saving algorithms is executed in OAM system and the other part of the algorithms is executed in NE.

The functionality ensured by OAM system and NE can be distinguished by the following aspects for a hybrid ESM solution:

a) Both OAM system and NE execute energy saving related measurements separately.

b) The decision to trigger energy saving actions is made at OAM system or NE level, and the trigger condition shall be combined the part from OAM system and the part from NE level, which needs OAM system and NE to exchange information related to decision making. For example, a scenario of decision making at NE level may be, when an "off-peak hours of a cell" policy is determined based on OAM system's historical statistics of a cell's traffic load, OAM system may configure it to NE to enhance the NE's local decision making to trigger energy saving actions.

For Example: At the NE level, the energy saving actions activation is initiated only when both conditions A1 and B1 are met:

A1: the current time resides at the off-peak hours of the cell;

B1: the current traffic load of the cell decreases under a threshold for a given duration.

Deactivation actions of energy saving are initiated only when either condition A2 or B2 is met.

A2: the off-peak hours of the cell is expired;

B2: the current traffic load of the cell increases above a threshold for a given duration.

It's also possible for OAM system to aggregate such decision-making information from OAM system and NE level, and make decision to trigger energy saving actions at OAM system.

c) No matter the decision is made at OAM system or NE level, the final executor of energy saving actions is NE.

The table below summarizes the features of hybrid ESM solutions.

Comparison Feature	Hybrid ESM solution
Energy saving related measurements	done by OAM system and NE separately
Decision making to trigger ES actions	Done at OAM system or NE level, combine both OAM system and NE's decision making to trigger energy saving actions
Energy saving action execution	NE

A hybrid ESM solution can be defined as follows:

Hybrid: In such solutions, decision making to trigger energy saving actions can be done both:

a) At the NE level: these decisions are taken locally at NE and may trigger energy saving actions at the NE level.

b) At OAM system: these decisions are taken at the OAM system.

Information related to decision making of Energy Savings Management shall be exchanged between OAM system and NEs and instructions from a OAM system to a NE may affect energy saving actions taken by that NE.

9 Analysis of potential OAM based solutions

9.1 Usage of existing standardized solutions

VOID

9.2 Need for defining new solutions

.VOID

10 Conclusions

In this study item the motivations of mobile network operators for the introduction of Energy Savings control mechanisms have been described.

The following use cases for achieving Energy Savings have been identified:

- ENB Overlaid
- Carrier Frequency Restricted
- Capacity-limited Network

- ENB Time Scheduled Switch Off/On

For the above use cases the energy saving states can be conceptually identified for the network element:

- notParticipatingInEnergySaving state: state in which no energy saving functions is in progress.
- energySaving state: state in which the network element is powered off or restricted in physical resource usage in other ways.
- compensatingForEnergySaving state: state in which the network element is remaining powered on, and taking over the coverage areas of geographically closed network element in energySaving state.

From a network management perspective, there may be different ways to implement the processes of enabling and disabling ESM determining the cells to enter or leave the energySaving state:

4. Centralized energy saving management
5. Distributed energy saving management
6. Hybrid energy saving management.

Based on the outcome study, normative work is needed. It is necessary to determine the usage of existing IRPs for the purpose of Energy Savings Management as well as potential definition of new IRP.

Annex A (informative): Evaluation of the energy saving potential

The study considers downlink data traffic only, handled via HSDPA technology. The table below lists the key model parameters. The inter-site distance has been chosen such that UL/DL coverage requirements are met even for the case of 12 active sites (assuming a downtilt optimised for the case of 48 active sites).

Table A-1 List of the Key Parameters

SYSTEM MODEL		PROPAGATION MODEL	
# of sites	12, 24, 36 or 48	Path loss	$123.22 + 35.22 \log_{10} d_{km}$
Inter-site distance	1100 m (based on 48 sites)	Antenna diagram	Kathrein 741989
Downtilt	4^0	Main lobe gain (including slant/feeder loss)	11.5 dBi
Carrier bandwidth	5 MHz		
# Carriers/sector	i = 1, 2, 3, 4	Indoor loss	8 dB
P_{max}	i × 20 W	$\sigma_{shadowing}$	6 dB
P_{CPICH}	i × 2 W	Inter-site shadowing correlation	0.5
TRAFFIC HANDLING		Orthogonality factor	0.10
Rate adaptation	$\min\{i \times 21.6, i \times 5 \times \log_2(1 + SINR)\}$	Noise figure	8 dB
Packet scheduling	Round robin	Noise temperature	288 K

A typical traffic load variation over a 24 hour period is assumed, as depicted in Figure A.1.

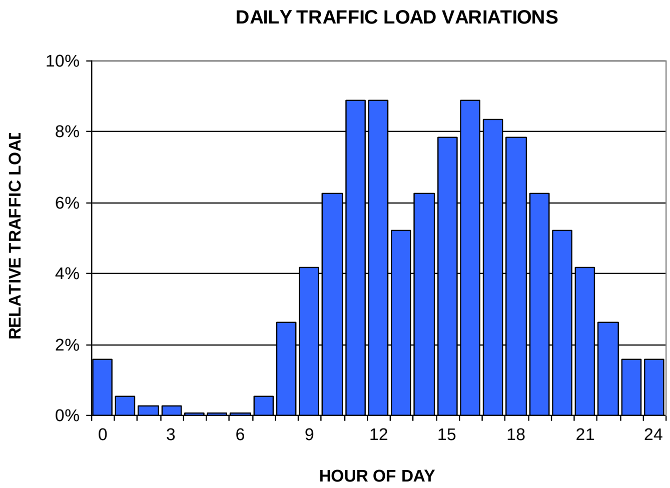

Figure A.1 Daily traffic load variation

Determining the maximum supportable load for a given quality target

For each of the network configurations in Figure 4.2.1 , i.e. $k \in \{48, 36, 24, 12\}$ and $i \in \{4, 3, 2, 1\}$, it has been determined the downlink user throughput performance (average and 10th cell edge percentile) versus the network-wide average number of active data flows. The results are presented in Figure A.2 . Besides the throughput results, the charts also show the observed activity factor, i.e. the average transmit power of a sector. Observe that the experienced throughputs are higher for lower traffic loads, a higher number of active sites and more available spectrum, all as expected. Furthermore, the cell edge throughput percentiles (dashed curves) obviously lie below the average throughput curves (continuous curves). For a given number of active sites, the activity factor is independent of the available spectrum and increasing in the traffic load.

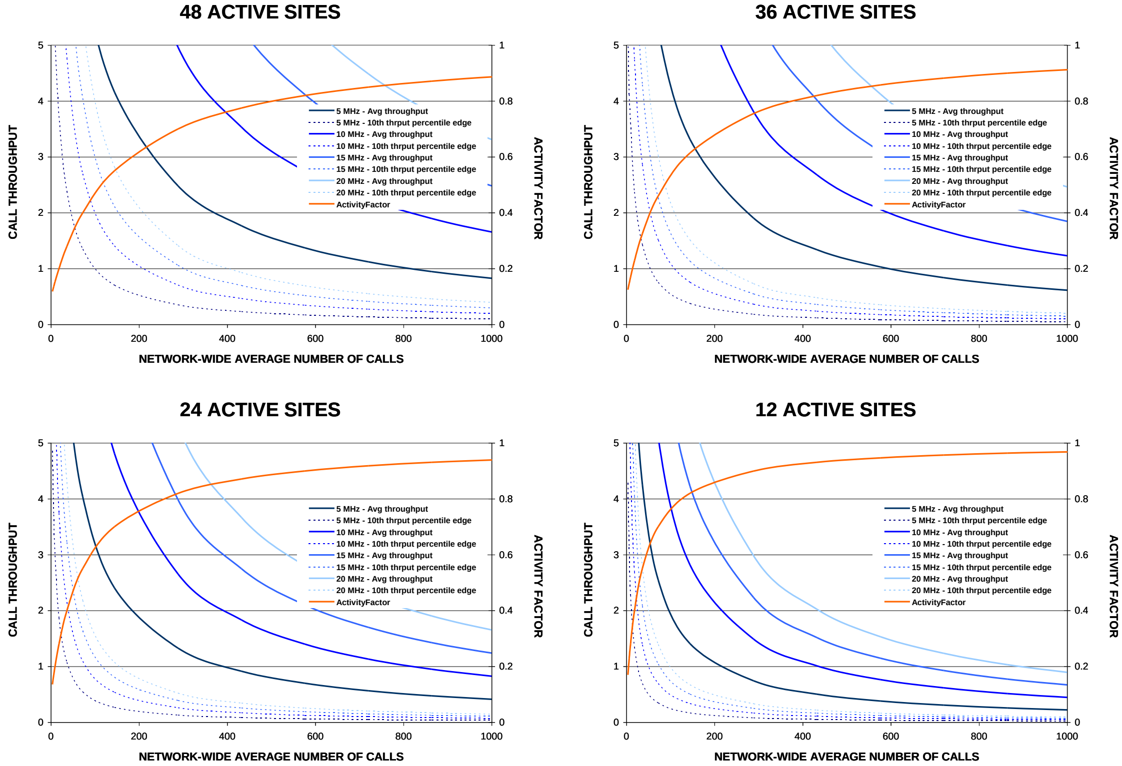

Figure A.2 Average user and 10th percentile cell edge throughput for configurations with 48, 36, 24 and 12 active sites and 5, 10, 15 and 20 MHz of available spectrum.

Assuming a target level of 250 kbit/s for the 10th throughput percentile at the cell edge or, alternatively, a 1 Mb/s target level for the average user throughput, the maximum supported traffic load is determined for each configuration (in terms of the number of active sites and the available spectrum). These results are presented in. Figure A.3. Observe that, even if the target levels are quite asymmetric, the supportable traffic is significantly higher when considering a target on the average user throughput, rather than on the 10th cell edge throughput percentile.

Observe further that in distinct scenarios with the same number of deployed sector-carriers (the number of sectors × the number of carriers), it is not trivial which configuration supports the highest load. For instance, if we compare a configuration with 24 active sites and 3 carriers per sector (216 sector-carriers) with a configuration with 36 active sites and 2 carriers per sector (also 216 sector-carriers), the former configuration supports the highest traffic load, i.e. rather more carriers than more sites. On the other hand, if a configuration with 24 active sites and 4 carriers per sector (288 sector-carriers) is compared with a configuration with 48 active sites and 2 carriers per sector (also 288 sector-carriers), it is the latter configuration that supports the highest traffic load, i.e. rather more sites than more carriers.

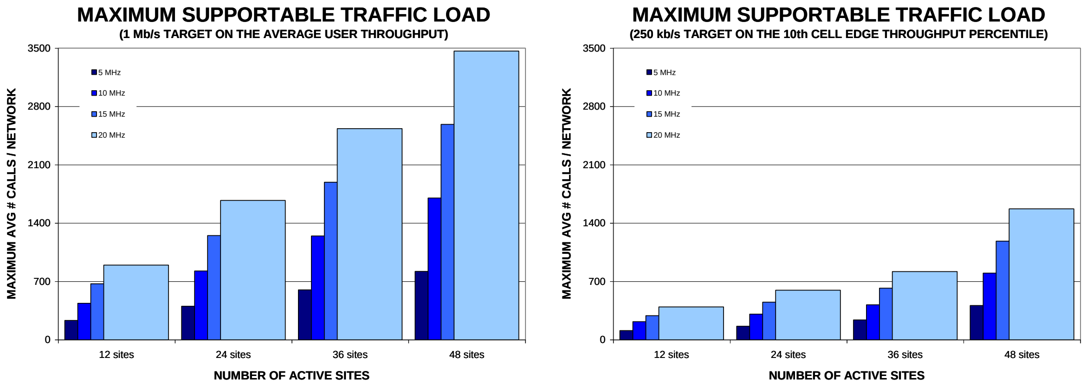

Figure A.3 Maximum supportable traffic load for each configuration, assuming a 1 Mbit/s target on the average user throughput (left chart) and a 250 kbit/s target on the 10th cell edge throughput percentile (right chart)

The final step is to use these results to determine the most energy-efficient network configuration to provide the set performance targets for each hour of a 24 hour day. Assuming an adequately planned network, we set the peak hour traffic load equal to the supportable traffic load in a scenario with 48 active sites and 20 MHz spectrum (four carriers). For the case of a 250 kbit/s target on the 10th cell edge throughput percentile, this gives a peak hour traffic load of about 1572 active data flows (throughout the network), while for the case of a 1 Mbit/s average user throughput target, this gives a peak hour traffic load of about 3466 active data flows. Considering the assumed daily traffic load fluctuations as depicted in Figure A.1, this immediately translates to a setting of the absolute traffic load in each hour of the day/night.

We first need to define the assumed energy consumption model, which translates the number of active sites, the number of active carriers (in an active sector) and the activity factor to an aggregate (network-wide) energy consumption level. Denote with S_{on} the number of active sites and with S_{off} = 48 – S_{on} the number of inactive sites. Futher denote with C_{on} the number of active carriers (in an active sector) and with C_{off} = 4 – C_{on} the number of inactive carriers (in an active sector). Finally, let γ denote the activity factor. The applied energy consumption model is characterised by four parameters:

- P_{AC} is the energy consumption of a fully active air conditioning unit per site;
- $P_{CARRIER}$ is the energy consumption per fully active carrier (for the entire site); this captures all energy consumption not related to the air conditioner;
- α is the fraction of P_{AC} that is the minimum energy consumption of an air conditioning unit, regardless of the site's (in)activity or the sector's activity factor ;
- β is the fraction of $P_{CARRIER}$ that is the minimum energy consumption of a carrier, regardless of the carrier's (in)activity or the sector's activity factor.

Applying a lineairity assumption of energy consumption w.r.t. sector activity, the following formula is used to determine the energy consumption:

$$E = S_{off}\left(\alpha P_{AC} + 4\beta P_{CARRIER}\right) + S_{on}\left(P_{AC}\max\{\alpha, \tfrac{1}{4}C_{on}\gamma\} + C_{on}P_{CARRIER}\max\{\beta,\gamma\} + C_{off}\beta P_{CARRIER}\right),$$

The part $S_{off}\left(\alpha P_{AC} + 4\beta P_{CARRIER}\right)$ covers the energy consumption of inactive sites (all capable of using four carriers). The second part covers the energy consumption of the active sites, where:

$P_{AC}\max\{\alpha, \tfrac{1}{4}C_{on}\gamma\}$ covers the energy consumption of the air conditioning dependent on the activity per carrier.

$C_{on}P_{CARRIER}\max\{\beta,\gamma\}$ covers the energy consumption of the active carriers dependent of the activity per carrier.

$C_{off}\beta P_{CARRIER}$ covers the energy consumption of the inactive carriers at the active site.

If it is assumed that P_{AC} = 1500 Watt and $P_{CARRIER}$ = 750 Watt, while we consider different choices of α and β, while the activity factor γ is readily obtained from the simulations (see also Figure A.2). Considering only the scenario with the performance target on the 10th cell edge throughput percentile, for the case of $\alpha = \beta$ = 10% the results in Figure

4.2.2 in the main text shows for each hour of the day the energy consumption level if we constantly deploy a configuration with 48 sites and 4 carriers, as well as the energy consumption level if in each hour of the day the most energy-efficient configuration is deployed (which still satisfies the imposed performance target).

Annex B (informative): Change history

Change history								
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Cat**	**Old**	**New**
Dec 2009	SA#46	SP-090740	--	--	Presentation to SA for information	--	---	1.0.0
Mar 2010	SA#47	SP-100069	--	--	Presentation to SA for approval	--	1.0.0	2.0.0
Mar 2010	--	--	--	--	Publication of SA approved version	--	2.0.0	10.0.0