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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Introduction

The need to reduce emissions and to include energy efficiency as a new paradigm of industrial development is widely acknowledged. In this context the mobile industry is making efforts to deploy energy efficient networks. In the Mobile Green Manifesto 2012 it is stated that mobile industry will reduce its Green House Gas (GHG) emissions per every connection by 40 % by 2020. Even if in this forecast all the variables in the mobile context are taken into account altogether, it is estimated that 80 % of the energy consumption and GHG emissions of the mobile scenario are due to networks. Studies and recommendations in this context are then highly valuable.

Moreover, it is reported from other sources (see [i.1]) that 3 % of current world-wide energy consumption is due to ICT, which causes about 2 % of the overall CO2 emissions. Since mobile broadband data usage has experienced significant growth and a thousand time expansion is expected by 2020, the consequence could be a significant increase of power consumption of mobile networks.

The present document addresses mobile network level Radio Access energy efficiency measurements, and aims to assess the complexity of these measurements both in real networks and in laboratory environments. The focus is on mobile radio access networks, even if the alignment with Network Efficiency measurements in other contexts is deemed as appropriate. Moreover the analysis is based on "partial" networks (as they are defined in the present document), with an hint on how to extend the results to wider ("global") networks.

As for measurements in real networks, the report will study the most appropriate models to describe energy issues in radio access networks and will introduce measurement definitions to validate these models. Data availability for models and measurements will be checked.

As for measurements in laboratory environments, the report will consider the level of complexity that energy efficiency measurements will impose, under the assumption they are an extension of pre-existing single node energy efficiency measurements (like those defined in [i.2]).

The need for network level energy efficiency measurements is widely acknowledged, both as an extension of energy efficiency evaluations on single nodes and as a "building block" for energy efficiency estimations of entire communications networks.

On one hand, there are radio access features whose impact on energy efficiency cannot be fully estimated while considering single node measurements only. As examples, we can cite RRM procedures, interference management, Coordinated MultiPoint (CoMP), relay nodes management, heterogeneous network deployment, DTX methods, and D2D/M2M techniques.

On the other hand, the radio access network is considered to be one of the most significant contributors to the energy consumption of the entire communications network due to its extensive deployment. To form a complete view of network energy efficiency, the radio access portion has to be considered properly and correct estimation of its energy consumption is needed.

The present document, in defining and describing network level energy efficiency, can be beneficial for different reasons:

- get an accurate measurement (rather than a statistical estimate) of radio network energy consumption and efficiency;
- help radio access network operators understand and consequently improve the energy efficiency of their networks, taking into consideration also the quality of service and quality of experience from the served users;
- enable radio access equipment vendors to demonstrate and improve energy efficiency features under real conditions.

Throughout the present document it has to be pointed out that none of the statements made here are intended to specify models, metrics or measurements procedures, but just to report them from a theoretical point of view, aiming to highlight the feasibility of these various issues. Every definition of these issues will be possibly performed when and if a different phase will be started in the Group, aiming at a Technical Specification purpose. Consider that some topics dealt with in the present document could need more detailed analysis in case of an evolution towards a Technical Specification.

The present document is organized as follows. First of all an analysis of the possible metrics to be adopted for network level energy efficiency (clause 5) is presented, including an overview of the data available to build these metrics under real network conditions (power consumed and throughput information). Clause 6 presents the measurement methods in real networks as far as the studies have identified them so far, either from network inspection or relying on the users data. Clause 7 reports the outcome of the evaluations made during the Technical Report lifetime about laboratories network level measurements, with the recommendations on which an agreement has been reached. Next, in clause 8, a method to extend the measurements made in the framework of partial network scenarios, following in particular the ideas developed within the FP7 European Project EARTH and the method called E3F elaborated therein, is presented, with an example about how to have figures of energy efficiency estimation in global networks. Finally a clause about Recommendations for future work is given and the Report is completed by annexes dedicated to the main European projects helpful in the preparation phase of the work (namely, EARTH and OPERA-Net).

1 Scope

The present document is about network level energy efficiency measurements, aiming to assess the complexity of these measurements in real networks and in laboratory environments for the radio access networks framework. The radio access is deemed to be the most relevant energy consumption source in mobile networks. In particular the focus of the present document is on the "partial" radio access networks, representing a part of the whole network where the tests are to be performed; possible extension to wider networks ("global" in the following) is taken into consideration as well. In the networks analysed in the present document the considered elements are the so called "radio base stations", including any possible representation of them, but excluding radio network controllers, backhauling or any equipment connecting nodes to the core network. Energy efficiency of the User Equipment is not considered as well. Availability of data useful to estimate energy efficiency in the network is dealt with as well in the present document. The content of the present document is not intended to specify models, metrics or measurements procedures, rather to report them from an analytical point of view, aiming to highlight the feasibility and effectiveness of the various options.

The radio access technologies considered in the report under study are mobile networks such as GSM, WCDMA and LTE.

The present document also includes recommendations on possible future standardization work in the domain of wireless network energy efficiency assessment.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] KTHGenoa: "Energy Efficiency Measurements at the Network Level", Anders Västberg, Mats Nilsson, Guowang Mio, Claes Beckman, Ki Won Sung, Jens Zander, 1st ETSI TC EE Workshop, 20-21 June 2012, Genoa Italy.

[i.2] ETSI TS 102 706: "Environmental Engineering (EE) Measurement Method for Energy Efficiency of Wireless Access Network Equipment".

[i.3] "Energy efficiency KPIs for network measurement", Erik Friman, Ericsson; 1st ETSI TC EE Workshop, 20-21 June 2012, Genoa Italy.

[i.4] OPERA-Net project information.

NOTE: Available at http://www.celtic-initiative.org/Projects/Celtic-projects/Call5/OPERA-Net/operanet-default.asp.

[i.5] OPERA-Net2 project information.

NOTE: Available at http://www.celtic-initiative.org/Projects/Celtic-Plus-Projects/2011/OPERA-NET2/operanet2-default.asp.

[i.6] L.Saker, S-E Alayoubi (FT) & H-O Scheck (NSN): "System selection and sleep mode for energy saving in cooperative 2G/3G networks", VTC fall 2009, Alaska, September 09.

[i.7] Gilbert Micallef, et. al (NSN): "Energy efficiency evolution of mobile networks", VTC spring 2011.

[i.8] EARTH project summary leaflet.

NOTE: Available at www.ict-earth.eu.

[i.9] Project Summary.

NOTE: Available at https://www.ict-earth.eu/news/events/2012-07-06-EARTH%20Project%20Presentation%20SummaryFNMS_12.pdf

[i.10] EARTH public deliverables.

NOTE: Available at https://www.ict-earth.eu/publications/deliverables/deliverables.html.

[i.11] "How Much Energy is Needed to Run a Wireless Network?", G. Auer et al. IEEE Wireless Communications Magazine Special Issue on Technologies for Green Radio Communication Networks. IEEE, Oct 2011.

[i.12] "How much energy is needed to run a wireless network?" G. Auer et al., in "Part I: Communications Architectures and Models for Green Radio Networks" of "Green Radio Communication Networks". Cambridge University Press, to appear Mai 2012.

[i.13] "Flexible power modeling of LTE base stations", C. Desset, B. Debaillie, V. Giannini, A. Fehske, G. Auer, H. Holtkamp, W. Wajda, D. Sabella, F. Richter, M.J. Gonzalez, I. Gódor, (P. Skillermark), M. Olsson, M. Imran, A. Ambrosy, O. Blume, IEEE WCNC 2012, Paris, April 2012.

[i.14] "Base Station Power Model", NTT DOCOMO, Alcatel-Lucent, Alcatel-Lucent Shanghai Bell, Ericsson, Telecom Italia, R1-114336, TSG-RAN WG1 #67 San Francisco, USA, November 14-18, 2011.

[i.15] "How green is my network? The E3F Energy Efficiency Evaluation Framework". O. Blume, EARTH Training Workshop, Grenoble, June 13th, 2012.

NOTE: Available at https://www.ict-earth.eu/news/events/2012-06-EARTH%20Training_WS_Estimation_Savings.pdf

[i.16] GSMA benchmarking service.

NOTE: Available at http://www.gsma.com/publicpolicy/mobile-energy-efficiency/mobile-energy-efficiency-resources/.

[i.17] 3GPP TR 36.814: "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects".

[i.18] ITU-T Recommendation P.1201: "Parametric non-intrusive assessment of audiovisual media streaming quality".

[i.19] ITU-R Report M.2135: "Guidelines for evaluation of radio interface technologies for IMT-Advanced".

[i.20] 3GPP TR 36.805: "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Minimization of drive-tests in Next Generation Networks".

[i.21] 3GPP TSG-RAN WG2 Meeting #78: "Summary of [77bis#21] Joint/MDT: Scheduled IP Throughput measurement scope".

[i.22] 3GPP TS 36.314 change request CR 0027: "Introduction of MDT measurements", TSG-RAN WG2 Meeting #79.

NOTE: Available at http://www.3gpp.org/ftp/tsg_ran/WG2_RL2/TSGR2_79/Docs/R2-124358.zip.

[i.23] 3GPP TS 37.320 change request CR 0046: "Updates for MDT enhancements", TSG-RAN2 Meeting #79.

NOTE: Available at http://www.3gpp.org/ftp/tsg_ran/WG2_RL2/TSGR2_79/Docs/R2-124353.zip.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

activity level: reflection of the amount of time (as a percentage of the total) during which data is generated by the server and sent to the UE (or UE group) with the highest path loss

busy hour: period within a given 24-hour period during which the maximum RBS total load in a given 24-hour period occurs

busy hour load: average RBS load during the busy hour

distributed RBS: RBS architecture which contains radio heads (RRH) close to antenna element and a central element connecting RBS to network infrastructure

energy efficiency: relation between the useful output and energy/power consumption

Integrated RBS: RBS architecture in which all RBS element are located close to each other for example in one or two cabinets

NOTE: The integrated RBS architecture may include Tower Mount Amplifier (TMA) close to antenna.

low load: average RBS load during time when there is very low traffic in network

medium term load: defined RBS load level between busy hour and low load levels

power consumption: power consumed by a device to achieve an intended application performance

power saving feature: feature which contributes to decreasing power consumption compared to the case when the feature is not implemented

Radio Base Station (RBS): network component which serves one cell or more cells and interfaces the user terminal (through air interface) and a wireless access network infrastructure

telecommunication network: network operated under a license granted by a national telecommunications authority, which provides telecommunications between Network Termination Points (NTPs)

wireless access network: telecommunications network in which the access to the network (connection between user terminal and network) is implemented without the use of wires

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC	Alternating Current
ACK	See TCP acronym.
BCCH	Broadcast Control CHannel
BH	Busy Hour
BS	Base Station
BSC	Base Station Controller

BTS	Base Transceiver Station
CCH	Common Channel
CDF	Cumulative Distribution Function
CELTIC	Industry-driven European research initiative
CPICH	Common PIlot Channel
CRAN	Cloud RAN (or C-RAN)
CS	Circuit Switched
DC	Direct Current
DL	DownLink
DPCH	Dedicated Physical Channel
DPI	Direct Packet Inspection
DSP	Digital Signal Processing
DTX	Discontinuous Transmission
EARTH	Energy Aware Radio and neTwork tecHnologies
EDGE	Enhanced Datarate GSM Evolution
EUREKA	European Research Coordination Agency
eUTRAN	Evolved UMTS Terrestrial Radio Access Network
FIN	See TCP acronym.
GBR	Guaranteed Bit Rate
GERAN	GSM/EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GHG	GreenHouse Gas
GSM	Global System for Mobile communication
GSMA	GSM Association
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HTTP	HyperText Transfer Protocol
HVGA	Half-size Video Graphics Array
HW	HardWare
ICT	Information Communications Technology
IP	Internet Protocol
ITU	International Telecommunications Union
JCNC	Joint Channel and Network Coding
KPI	Key Performance Indicator
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MEE	Mobile Energy Efficiency
MIMO	Multiple Input Multiple Output
MOS	Mean Opinion Square
NA	Not Applicable
NMS	Network Management System
O&M	Operation & Maintenance
OAM	Operation And Maintenance
OEM	Original Equipment Manufacturer
OPERA-Net	Optimizing the Power Efficiency of Radio Access Networks
OS	Operative System
OSS	Operations Support Systems
PA	Power Amplifier
P_{BB}	base band power consumption
PDF	Probability Distribution Function
PER	Peak Error Rate
PM	Performance Management
P_P	power consumption of the digital processing unit
P_{RF}	maximum RF power
PS	Packet Switched
P_{TRX}	fixed power consumption of the radio module
QCI	QoS Class Identifier
QCIF	Quarter Common Intermediate Format
QoE	Quality of Experience (end-user)
QoS	Quality of Services
RAB	Radio Access Bearer

RAN	Radio Access Network
RAT	Radio Access Technology
RBS	Radio Base Station
RF	Radio Frequency
RNC	Radio Network Controller
RRH	Remote Radio Head
RRM	Radio Resource Management
RX	Receiver
SGW	Serving Gateway
SME	Small and medium-sized enterprises
SOTA	State Of The Art
SW	SoftWare
SYN	See TCP acronym
TCP	Transmission Control Protocol

NOTE: ACK, SYN and FIN are signalling in the TCP session.

TRX	Transceiver
TV	TeleVision
TX	Transmitter
UDP	User Datagram Protocol
UE	User Equipment
UL	UpLink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WP	Work Package
XML	Extensible Markup Language

4 Definition of the network in the scope

The overall positioning of the present document is graphically represented in Figure 1.

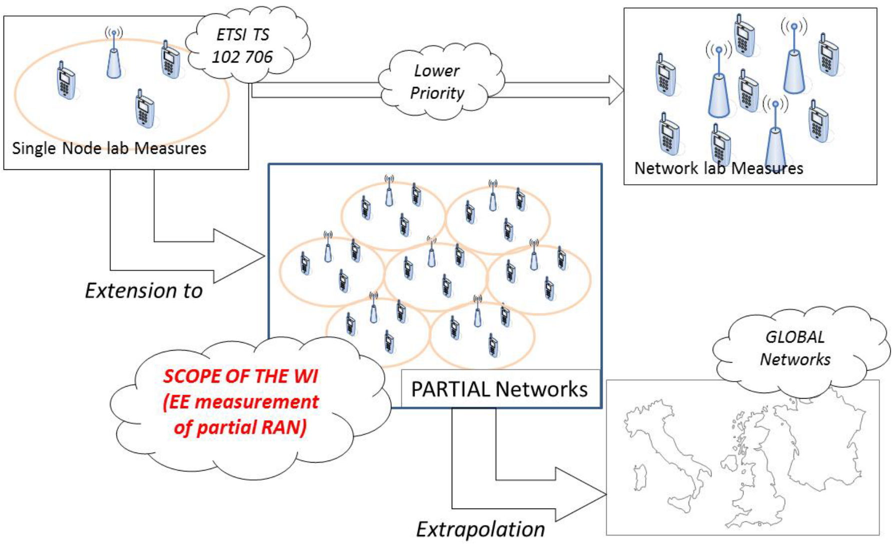


Figure 1: Graphical representation of WI scope

Specifically, the present document will build upon existing ETSI Standards, such as TS 102 706 [i.2] for single node energy efficiency, evolving towards the definition of energy efficiency models and metrics for small portions of the radio access networks. The commonly accepted definition of "access network" is adopted in the present document, consisting of that part of the mobile network that connects the User Equipment to the Core Network (GERAN in GSM/EDGE, UTRAN in WCDMA, eUTRAN in LTE). For the sake of simplicity and to build upon TS 102 706 [i.2] the BSCs in GSM/EDGE networks and the RNCs in WCDMA networks are not considered in the tests and measurement methods for energy efficiency purposes, nor are any backhaul segments or contributions from User Equipment.

A graphical representation of what is defined in the present document as the "access network" is shown in Figure 2, where the RNC/BSC/SGW are drawn for completeness but are out of the scope of the energy efficiency evaluations within the present document.

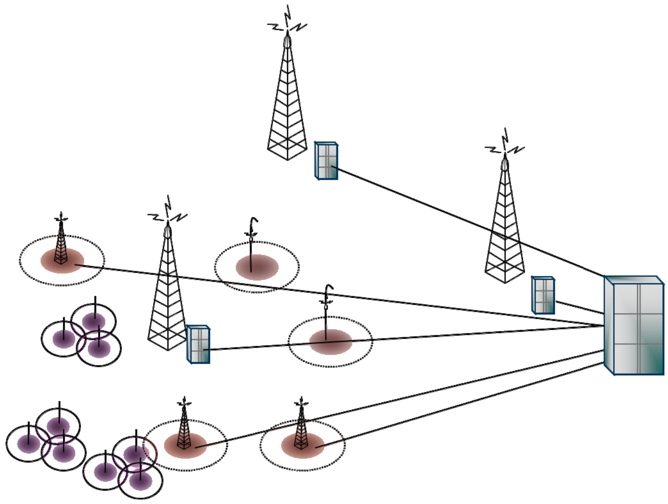


Figure 2: Graphical representation of the access network under study

Evolving from small parts of the access networks proper extrapolation can be attempted towards the definition of Energy Efficiency for complete access networks, such as the network of an operator in a country or anyway an aggregation in a wide scale framework.

5 Metrics and data for network level energy efficiency

In this clause the issue of which kind of metrics could be the most suited one for network energy efficiency measurements, in the particular case of the network in the scope of the present document, is dealt with. A definition of proper metrics that could be followed in the measurement tests is given in the clause.

5.1 Metrics and energy efficiency in literature

An important objective in the design of cellular systems is to maximize the number of bits that can be delivered over a certain time and in a given bandwidth; in this sense the throughput delivered in a given area and in such a bandwidth is deemed as an appropriate way to estimate the performance of a network. The operation of the network is not required to maintain overall throughput but it is also required to keep control of the perceived user quality. However quantifying the end user's perceived quality may sometimes be difficult since the suitable metric typically depends on the service or application being accessed.

Energy is considered a scarce resource that should be carefully utilized and thus energy consumption is considered in the analysis. But the spectrum efficiency and the quality aspects are still important, so the analysis is a multi-dimension one and it will sometimes be needed to trade one desired property for another, e.g. quality versus energy consumption.

In 3GPP quality performance metrics have been defined (see [i.17]), both for the case of full buffer traffic and for the case of variable traffic. In particular, for the former case, the metrics that are suggested in 3GPP are:

- mean user throughput;
- throughput CDF;
- median and 5th percentile (worst) user throughput.

For variable traffic instead the 3GPP suggests as possible metrics:

- mean, 5th, 50th, 95th percentile user throughput;
- served (cell) throughput;
- harmonic mean normalized cell throughput;
- normalized cell throughput;
- resource utilization.

In TS 102 706 [i.2] for RBSs the "quality" is taken into account by ensuring a sufficient level of throughput for cell edge users in the context of the dynamic measurement set-up; if the cell edge users do not achieve a level of throughput above a given threshold the measurement is not considered. The traffic model that has been considered in the dynamic measurement set-up is not the full buffer model as it considers users that have alternated ON and OFF periods.

In available literature (see as a possible example, EARTH deliverable D2.2 [i.10]), three main metrics definitions can be found, depending on the focus of the measurement (which target to be addressed) and on which environment (urban, rural, etc.) the measurement is to be applied:

- successfully transferred data volume per unit time over consumed power (ε^{I});
- area unit over consumed power (ε^{A});
- number of users over consumed power (ε^{S});

and their definition is generally as follows:

$$\varepsilon_I = \frac{Data\_Volume\_per\_\sec}{Power} \text{ in } \left[\mathrm{bps}/\mathrm{W}\right]$$

$$\varepsilon_A = \frac{Coverage\_Area}{Power} \text{ in } \left[\mathrm{m}^2/\mathrm{W}\right]$$

$$\varepsilon_S = \frac{Number\_Of\_Users\_per\_\sec}{Power} \text{ in } \left[\mathrm{n\_users}/\mathrm{W}\cdot\mathrm{s}\right]$$

Data volume per unit time over power consumed (ε^{I}) takes into consideration the achieved information exchange versus the consumed power in the area where ε^{I} is computed. It has to be taken into consideration that there is power consumption even if traffic is null (note that the metric is always zero when there is no traffic). This metric is thus relevant for high traffic situations and for capacity-limited settings (urban areas). Only traffic of satisfied users, namely users with a level of QoS/QoE above pre-defined thresholds, is to be taken into account as the traffic of unsatisfied users is useless (see note in clause 5.2).

Area unit over consumed power (ε^{A}) is otherwise important at low loads where systems are coverage limited and it is therefore useful in case rural area scenarios. If the coverage area is kept fixed this metric is very reliable in terms of consumed power and comparisons are easy.

Number of users per unit time over consumed power (ε^S) could be an easy metric to be computed since the number of users is quite an easy number to determine even if it is variable over time; however this metric has to consider satisfied users (i.e. with a given QoS). A drawback of this metric is that it does not take into account the services and applications that are being accessed: voice, video and data users are given the same weight, and different sessions belonging to the same user are duplicated (may be an issue with smartphones).

An alternative metric could be the following (subject to further investigation):

$$\varepsilon_{SS} = \frac{Number\_Of\_Simult\_Scheduled\_Users}{Power} \text{ in} \left[\text{n\_users} / \text{W} \right]$$

The use of instantaneous data samples may be another approach considering that sampled measurements can be averaged without impact on the measurement units.

5.2 Proposal of metrics for network level energy efficiency

The above defined metrics can be used to estimate Energy Efficiency together with the total energy consumption of the network. Focusing in particular to ε^I and ε^S, as defined in previous clause the first metric addressing the energy efficiency as a ratio between offered throughput and consumed power in the area, the second as a ratio between number of users and consumed power to serve them, they can be written, in a network area and highlighting the effect of satisfied and unsatisfied users.

$$\bar{\varepsilon}_I = \frac{\sum_{i \in U_{QoS}} w_i}{\sum_{i \in d_{BS}} P_{BS,i}}$$

$$\bar{\varepsilon}_S = \frac{card(U_{QoS})}{T \times \sum_{i \in d_{BS}} P_{BS,i}}$$

where w^i is the throughput per user with a given minimum QoS, U^{QoS} is the set of users with a given minimum QoS in the area of the measurements represented by a number d_{BS} of nodes, U'^{QoS} is the set of users that do not have the minimum QoS requirement in the area of the measurements; card(U) is defined as the cardinality of set U. T is the observation time.

The proposed network metrics reflecting ε_{SS} defined in clause 5.1 would be:

$$\bar{\varepsilon}_{SS} = \frac{card(U_{QoS})}{\sum_{i \in d_{BS}} P_{BS,i}}$$

With regards to QoS, recognizing that it is difficult to specify a common QoS target for all kinds of users, QoS targets will have to be set class by class:

1) For all kinds of classes, users are not satisfied if they are blocked or dropped. For circuit switched services like voice or constant bit rate data, blocking and dropping are the only QoS measures.

2) For data services in HSDPA and LTE, an additional QoS metric is the throughput. We can differentiate between GBR services (like streaming) and non-GBR ones (like web browsing users). If a GBR is specified for the user, it is counted as satisfied by its throughput if it attains its GBR. Users that do not have a specified GBR are considered as always satisfied by their throughput as these are best effort users (setting a target throughput for them is too random to be considered in a metric).

The definitions of $\bar{\varepsilon}_I$ and $\bar{\varepsilon}_S$ (stated in the formulas above) are based on the introduction of QoS for all users, to ensure the fairness of such measurements. The adoption of one of the above mentioned metrics will in general depend on a set of purposes, e.g. the aim of the test, the environment in which it is executed, or the availability of data. The suggested adoption of $\bar{\varepsilon}_I$ and $\bar{\varepsilon}_S$ is based on the objective to include QoS information in the metric, and depends very heavily on the availability of information to build such a metric. In the case in which this information is not available the differentiation among satisfied and unsatisfied users will not be possible and the traditional definition of metrics (namely ε^I or ε^S) could be used, even if this will be a subject of further discussion and research.

NOTE: Increasing base station load levels, $\bar{\varepsilon}_S$ or $\bar{\varepsilon}_{SS}$ may remain constant although the number of unsatisfied users is increasing. When this metric is used to determine a base station's capacity limit, a possible solution could then be to explicitly introduce throughput for unsatisfied users as a negative energy efficiency element as defined below:

$$\bar{\varepsilon}_S = \frac{card(U_{QoS}) + \eta\, card(U'_{QoS})}{T \times \sum_{i \in d_{BS}} P_{BS,i}}$$

$$\bar{\varepsilon}_{SS} = \frac{card(U_{QoS}) + \eta\, card(U'_{QoS})}{\sum_{i \in d_{BS}} P_{BS,i}}$$

where η is in the range [-1,0] and U'^{QoS} is the set of users in the measurement area for who the minimum QoS requirement is not satisfied.

This negative impact is already implicitly taken into account in $\bar{\varepsilon}_I$ as the throughput provided to unsatisfied users is taken from the satisfied users. For $\bar{\varepsilon}_I$, energy efficiency will therefore start to decrease with increasing number unsatisfied users.

6 Network level measurements in real networks

In clause 4 a definition of the network was provided; a network is a set of radio nodes in the Radio Access networks of mobile Radio Access Technologies, such as GSM, WCDMA and LTE. The objective of this clause is to describe how to perform energy efficiency measurements in such networks, according to the metrics and the constraints introduced in clause 5.

In particular this clause is dedicated to real network measurements (specifically measurements performed in operating networks loaded with real commercial traffic).

The measurement procedure to use will depend on the network information which can be collected and accessed for further analysis. One possible option is based on the nodes knowledge of user data throughput and making that information available to the operators. Another option is based on live test-users that perform real measurements in the operators' networks to estimate the efficiency by means of the parameters defined in the energy efficiency metrics.

The potential measurement methods require a selection of the network area in which to perform the measurements (according to the scope identified in clause 4), a selection of the quality of service threshold to ensure only valid users are considered (according to the metric definitions in clause 5), and a step-by-step procedure to be followed to perform the measurement.

6.1 Measurement procedure

Even if further analysis is needed in future stages, a procedure to make an energy efficiency measurement of real networks is introduced in this clause, with further details provided in clauses 6.2 to 6.4.

In particular, for real network measurements, the following steps are foreseen:

- *definition of the area of the measurement*. As stated the metric to evaluate energy efficiency should be built in a "partial" network area, according to the definition of the scope reported in clause 4. The definition of this area is the first issue to be taken into consideration. According to the extension to global area, as it will be described in clause 8, this partial area will be chosen in any of the geographical/sociological scenarios where the metric could be used;
- *observation time*. According to the metrics definition (see clause 5) a proper observation time should be introduced in order to capture the energy efficiency parameters of interest. This time should be long enough to include any possible variations that could affect throughput and power consumption (such as build-in energy efficiency measures in equipment), or changes in the number of users. In case of extension to global scale the measurement should be repeated, with the same observation time, in different periods of day and in different days in the year according to the load levels of the live networks to be investigated.
- *power consumption measurement in the area*. Within the framework of the above defined area and of the defined observation time the overall consumed power has to be measured, collecting information from all the equipment included in the mentioned area. For more details on this refer to clause 6.4.
- *QoE throughput and/or "satisfied" users estimation.* Always making reference to the area of the chosen "partial" network and within the observation time constraints it has to be computed the overall throughput and/or the number of users that could be defined as "satisfied" or "unsatisfied" according to the discussions kept in clause 5. For this estimation many different options are available, ranging from inspection of the network to the case of test users chosen to measure the network performance, and these options are described in clause 6.3.5.

6.2 Definition of the area of the measurement

In this clause a possible definition of the area to be considered as the reference for the measurement is attempted. A clause for reference is included of the area definition used in simulations. The partial area definition proposal is outlined but further definition needs to be agreed upon in further specification work. Additional details are therefore difficult to specify.

6.2.1 Area of measurement used in simulations

In simulations the concept of hexagonal tiers used to define reference areas; for measurement purposes the same concept could apply. Two "tiers" to be introduced:

- "small" tier made by 7 sites (the central one and 6 around – red in the figure);
- "large" tier made by 19 sites (the central one and 18 around – blue and red in the figure).

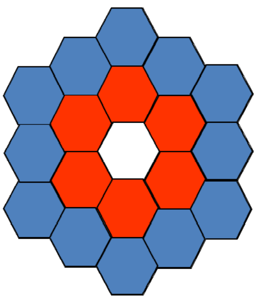


Figure 3: Standard homogenous hexagonal layout used for network simulations

It is worth noting that the above mentioned area definition is a very theoretical one, with clear drawbacks when it comes to real networks. In particular especially in case of heterogeneous networks (HetNet) there could be relevant problems to apply such area definitions. In such cases it could be considered an area with a given average traffic, disregarding the number of sites.

6.2.2 Partial area measurement definition proposal

A partial network could consist of a certain number of standard macro RBS single nodes (homogenous network) or a heterogeneous network with different RBS categories. A partial area might consist of a combination of macro nodes and smaller nodes. It is understood that there are many choices in implementation of a network that serves the traffic demand of a certain area.

From an energy efficiency measurement perspective it might be important to **not** specify the number of nodes or the type of nodes as the energy efficiency measurements for different network architectures are interesting to compare. The required number of nodes to fulfil a traffic amount might be less important as the performance part of the metric is measured from a UE or user perspective.

The partial area selection may be selected based upon a number of criteria:

- a defined geographical coverage area;
- a coverage area served by one RNC;
- an area served by several RNC nodes.

A geographically defined areas is proposed to be defined by user densities:

- Dense urban.
- Urban (part of a city, e.g. Rome or Paris city centre inner circle).
- Sub-urban.
- Rural area.

The definition of the above mentioned different environments and the related user densities is in compliance with 3GPP correspondent definition (in its turn derived from ITU IMT.EVAL); see also clause 8 for more details on the users densities adopted in EARTH, in particular in deliverable D2.3 [i.10].

In the EARTH project (see annex B) an area definition was discussed for remote areas that are only dimensioned by coverage demands. Examples are parts of northern Sweden, Norway and Finland. This might be named "Remote rural area". The inclusion of such area is for further discussion in the specification work.

There are advantages in an area definition set by a RNC/BSC/SGW coverage as the counters in the network are located in the nodes belonging to the measured area. As a general rule only one RAT should be analysed at a time. It is also recommended that common site equipment for several RATs are counted as a share of the total power consumption. The share for GSM, WCDMA and LTE are to be defined but power meters for total site and each base station node is recommended. For multi-RAT base stations a share figure of the total radio communication has to be used and further defined.

The partial area definition is dependent upon the selected measurement set-up and the support of possible external systems for collecting data. The specification work will be expected to be an iterative process between the selected metric, the area definition and the measurement method.

6.3 Measurement set-up alternatives for QoS KPIs

There are many mechanisms that are possible to be used to make measurements in the network. Which option to be used or combined are for further studies.

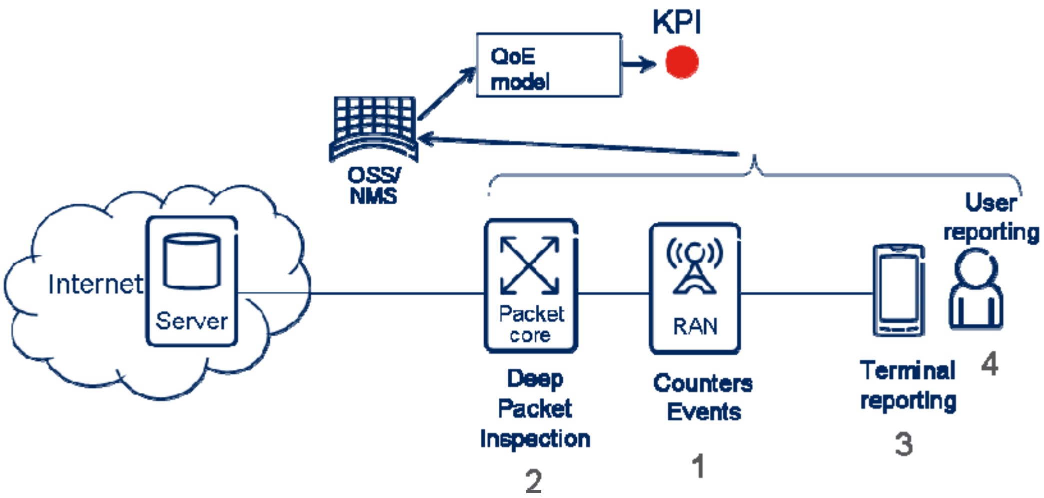


Figure 4: Options for performance measurement

The main options are indicated by the numbers in the figure:

1) Throughput measurement with network internal mechanisms.

2) Measurement by use of packet inspection with probes for obtaining application information (may be inspection of the header and/or payload).

3) Terminal reporting (MDT or special App).

An additional method to be considered is number 4 but as this involves user perceived quality this is different compared to measured qualities no 1 to 3.

4) Users reporting their experienced quality by interacting with a terminal application.

Each collected data is transferred to the O&M system. In the case of throughput measurement the UE throughput data is collected among other parameters measured in the RAN.

For QoE related parameters a model has to be used for weighting of the collected data by measurement tools or subjective data from end-users into a QoE model.

Quality of Experienced based measurements should use a model which weights the measured parameters. This model may be standardized by other organization (e.g. ITU-T) or based on an ETSI EE specification. For video there is ongoing standardization in ITU-T Recommendation P.1201 [i.18] which is used to estimate video QoE. A subset of the parameters in the model are listed below:

- Video Codec (H.264, or other codecs).
- Format: Video resolution QCIF, HVGA, etc.).
- Bitrate: coded video bitrate (kbps).
- Packet loss information: lost packets for video sample (~16 sec).
- Buffering events: Freezing of the video.

Other applications are in the standardization process such as web browsing.

6.3.1 Measurement with network internal mechanisms

In the metric clause it is suggested to use a metric that uses UE throughput as a KPI for QoS. UE throughput data is usually available in the mobile system which can be controlled and retrieved by the O&M system. The implementation of the data that is stored in the system for retrieval is a subject for each vendor. The O&M system can export the data to an external system for common handling of data regardless of the mobile system vendor.

Figure 5 shows a typical implementation for most vendors (the implementation refers to an implementation in an Ericsson system). The performance data are available in the mobile system as *counters* and *events*. Counters are available in the RBS (for LTE) and in the RNC nodes (for WCDMA) and events are recorded in RNC. There are many types of counters designed for many conditions in the radio access network while for energy efficiency measurements the performance counters are most interesting. Counter values are stored in memory every 15 minutes as a default but *events* have their own time stamp for the recorded data. Events can thus record data that have other frequencies than the 15 minutes interval. There is however a limitation set by the maximum storage of memory allocated for the event recording.

The *counters* are converted to XML files which are representations of HSPA throughput, R99 throughput and Erlang data for the cell or for the aggregated data on RNC level.

The *events* are stored in the RNC as a binary file which is converted to a text file by the O&M system (OSS). Event recordings can among other characteristics be setup to record UE or cell level throughput. Time stamp, event ID and user/cell ID are part of each record.

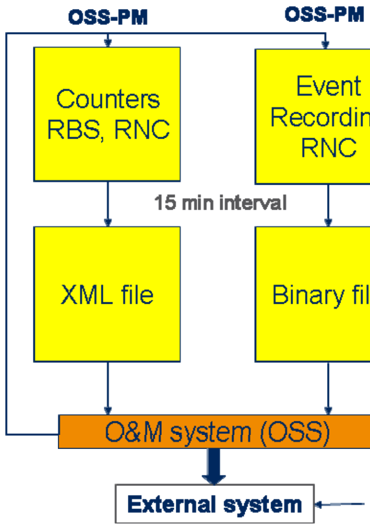


Figure 5: Counters from OSS

Measurement of aggregated throughput per cell is easy but measurement of each UE is more complex when number of users is extensive.

Measurement of throughput can be retrieved by making use of the internal system for data recording. The aggregated throughput for the cell is measured. If QoS/throughput has to be considered with users fulfilling a minimum bit rate should be measured, each UE has to be measured.

For the specified area to be measured all UEs need to be measured for classifying them as contributing to the aggregated throughput or not. This procedure might need to be supported by a script based software as the number of UEs to be measured might be extensive. The script could also calculate the aggregated throughput for the UEs fulfilling the criteria and for those not fulfilling.

6.3.2 Measurement from probes

In order to detect the application information of the data that is sent to the UEs it is necessary to retrieve information from the IP header. This function may be implemented by a Deep Packet Inspection, DPI function that contains all major functionalities as described below. Packet inspection and classification can be divided into three major groups:

1) IP and transport protocol header classification (a.k.a. 5-tuple inspection) inspects packets up to the Internet layer, the so-called 5-tuple:

   a) Source IP address (extracted from the IP header).

   b) Source port number (extracted from the transport protocol, e.g. TCP or UDP header).

   c) Destination IP address (extracted from the IP header).

   d) Destination port number (extracted from the transport protocol, e.g. TCP or UDP header).

e) Protocol (which indicates the Transport protocol, e.g. TCP, User Datagram Protocol (UDP), etc.).

2) Shallow inspection (a.k.a. Stateful inspection):

- Shallow inspection is usually described as analysis of Transport Level protocol state, by inspecting the current protocol header (TCP, UDP etc). E.g. analyzing the sequence of TCP header flags like SYN, ACK and FIN tells the state of the connection.

3) Deep packet inspection (DPI):

- Analysis of data content on the Application Layer, e.g. hypertext transfer protocol (HTTP) state, video frame content, etc.

The core network contains among other nodes GGSN nodes and backbone routers. Both those nodes are usually implemented on the same router platform. The router contains functionality that can be activated that checks the header information and forwards the selected packets to an external interface. To the external interface a server node might perform additional operation of the forwarded data.

There are also probes that can be connected to any interface independently of the router nodes.

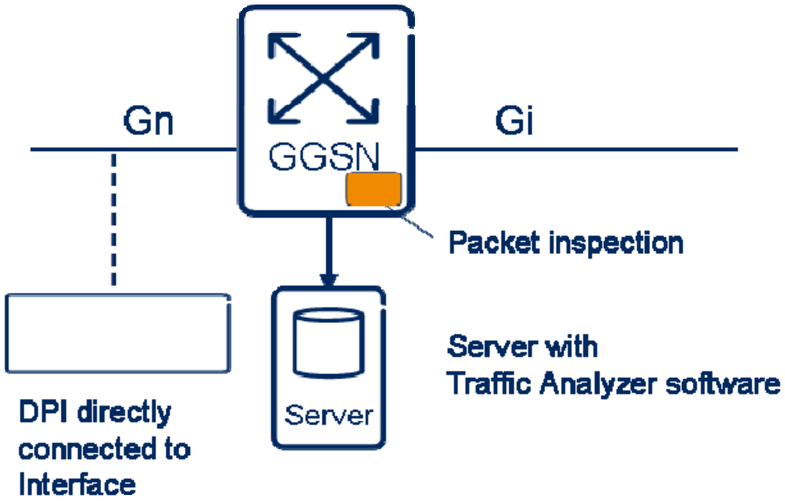


Figure 6: Implementation example of core network probes

Traffic analyzer software is available from a large number of vendors and from open sources such as Wireshark. It may even be possible to develop a specific software for energy efficiency measurement.

6.3.3 Measurement from terminal reporting

Network optimization after a network is operational is generally done by drive testing. In the drive testing test UEs collects measurements and location information while the test UEs is being driven in a car. The collected information is used offline to analyse the coverage in different locations and based on that the radio parameters, antenna locations, etc. are optimized. After the changes to any of the parameters, the drive test has to be performed again to verify that the changes are positive. Using drive tests for network optimization is expensive so automated solutions are preferred involving UEs in the network. The 3GPP studies have shown that it is beneficial to collect UE measurements to enable a more efficient network optimization.

The 3GPP release 11 includes QoS measurements. QoS includes scheduled IP throughput which may be used for energy efficiency KPI calculations. The MDT measurements (see annex C for more details) may be combined with measurements performed by other methods as described in other clauses. The MDT measurements do not contain any information about the application. For more details on MDT see metric clause.

MDT as a standardized functionality will probably be integrated in the lower layers of the UE or in the operative system of the Smartphone. There is however a possibility to add the measurement functionality needed for energy efficiency network performance aspects in a separate application. It is possible to add functionality not included in MDT but extend from the data provided by MDT. A typical Android Smartphone with the operative components is shown below.

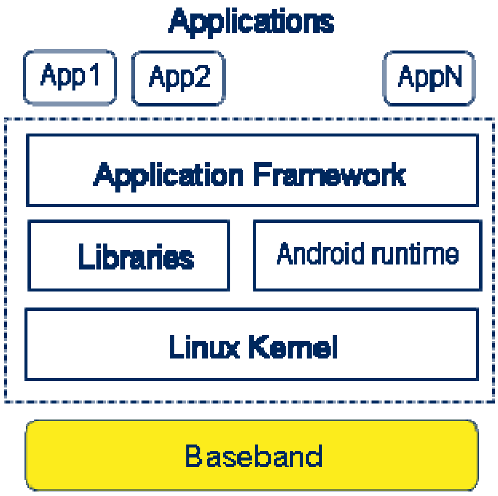


Figure 7: Example of UE with Apps in Android OS

The dashed box contains the Android OS while the Baseband is part of the UE. The Apps on top of the OS are designed by different companies and have extensive support by developments tools. The development time for Apps is typically months or less than one year. The Apps do not have the same level of control on the baseband as the Android OS which may define a limitation of the functionality that is possible to be included by an App for energy efficiency measurement.

For iPhone a similar structure and conditions exists for OS and Applications.

6.3.4 Measurement by end user evaluation

QoE may be evaluated by the end user. Even if the input is subjective due to the individual users attitude a reliable result can be obtained when a large number of users are involved in the test. This has been in use for evaluation of voice codecs in lab environment for many years and the result has been documented in MOS values (Mean Opinion Square). This solution has many drawbacks as it depends on the voluntary participation of the end-user in the test. This effect may however be minimized if the number of users in the selected area is sufficiently large. If dedicated test-users are used, instead, a more reliable result from each UE can be expected, as discussed in clause 6.3.5, but the limited number of test UEs gives less accurate statistical data.

One possible implementation of a user evaluated performance could be supported by an App that is initiated after a finished session, a video, voice or other session. The App could initiate a dialog which asks for a value 1 to 5 to be typed that reflects the perceived quality. The performance data (throughput, codec, etc.) for the session that is finished and evaluated could then be part of the transfer of reported QoE session user data.

6.3.5 Measurement by dedicated test user evaluation

Another alternative could be that of having special dedicated test users to execute the EE test. The dedicated test users have special test equipment UEs. The setup presumes that a very limited area is selected for test so that the number of test users are minimized as this will result in high cost for the EE network measurement. This alternative was formulated in the beginning of the WI and could be considered obsolete as the awareness of better methods is more mature.

Anyway, this kind of measurement could present some advantages, in particular it matches current TS for lab test (TS 102 706 [i.2]) and it presents limited complexity (1RBS, considered as a sample, while the surrounding are only RBS interferers).

On the other hand some drawbacks have to be taken into account, in particular the fact that only limited accuracy could be achieved, and also that these measurements are:

- only accurate for homogeneous networks with one type of BTS configuration and they do not;
- cope with heterogeneous networks.

6.3.6 Measurement by combining system tools and network UEs

In this method data is combined from several measurements. The combined result may give a better result compared to a single source or single method. One example of combination is to use network UEs connected to the network together with data from counters and event reporting in RNC or with probes in the core network. As this possibility is not yet studied it is intended for further studies.

6.4 Power consumption measurements

The radio base station has been identified as the equipment with the largest total power consumption in a wireless network. Therefore it has been proposed to install power meters to every RBS of the network or partial network under investigation to get a more accurate power consumption measurement.

RBS power consumption could be either measured directly with a power meter at the main RBS supply input, or alternatively via RF power measurements and a RBS power model to calculate the supply power. Option one would require additional equipment, which increases material usage. Option two would be based on already implemented RF transmit power reporting and hence be possible without any further equipment. Such a solution would be less accurate and requires proper RBS modelling for every possible configuration, which could be finally very complex.

One of the main drawbacks of any build-in RBS power measurement solution is that it would only cover power consumption from the RBS. During a measurement campaign carried out within the CELTIC project OPERA-Net (see annex A), we observed that the 3G base station power consumption was in several cases only around 30 % of the total site power consumption. Most of the sites contain also other equipment, like 2G base stations, back-up systems, masthead lights, cooling, etc.

Obviously, a built-in power meter would be of limited use to an overall network power consumption measurement, as it leaves too many elements unaccounted for. To measure the true energy consumption and cost of energy usage, each site requires a (remotely readable) power meter. If more detailed power consumption figures are needed from the site a more accurate and cheaper solution would be to install a site power meter with multiple channels to measure additional sub-site power consumption.

6.5 EE KPI calculations from measurements

In the previous clauses 6.3 and 6.4, we discussed ways for obtaining measurements directly from the network. In this clause, we show how EE KPIs of clause 5 can be calculated based on these measurements.

6.5.1 Case of QoS measurements with network internal mechanisms

OSS counters give valuable information about traffic and QoS metrics. The following counters can be used for calculating EE KPIs of clause 5.2:

- Throughput (for counter ε^{I}): This can be calculated as the ratio between the counter "traffic volume" and the observation time. In general, there is a counter for constant bit rate traffic (R99 CS and PS traffic, expressed in Erlang) and another one for data traffic (HSDPA, expressed in Mbytes). Global traffic volume is computed as follows:

$$volume = \sum_{\text{R99 services s}} \text{traffic}_s \times rate(s) + HSDPA\ volume \qquad \text{(Kbits)}$$

Observation time is being chosen as averaged over the whole day or whole week. Note also that a seasonal effect has to be considered in the observation time (in some areas traffic is related as an example to holiday periods); perhaps a good way to keep track of this is to repeat the test in different periods of the year.

To the purpose of the definition of the metric as suggested in clause 5.2 the drawback of this metric is that it includes both satisfied and unsatisfied users, and it is not possible to distinguish between them as required in clause 5 for calculating ε^I.

- Number of satisfied users: values for numbers of satisfied and unsatisfied users are available from equipment counters. The counters are usually given as the numbers of successful and unsuccessful RAB establishments. Number of dropped RAB is also given as a counter. The number of satisfied users is thus:

$$nb\_satisfied\_users = nb\_RAB\_establishment\_demands - nb\_RAB\_blocked - nb\_RAB\_dropped$$

A drawback of using these counters is that the resulting KPI takes into account only blocked or dropped users are unsatisfied users, and does not consider the user perceived QoS (degraded video quality, low data rates, etc.). Another drawback is that, especially when you deal with smartphones, having an established RAB does not mean that the user is in communication, but that it is connected to the network (to send updates from time to time for instance). This exaggerates the number of users in the system.

Beware of not using the counters that give the number of active (scheduled) users, as these values are misleading for data traffic. Indeed, in data networks, when a base station is saturated, the number of users that are served by it explodes as each user will stay longer in the system in order to end its data communication. To give an example, consider two base stations that carry the same traffic. Obviously, the base station that is able to serve this traffic with high throughput will have less active users; the number of active users in parallel is thus inversely proportional to the efficiency. Note that, for streaming (with admission control) and voice traffic, the number of active users is an acceptable measure as each user is accepted only if it achieves its target throughput (it brings an additional throughput to the cell). However, these users are rarely alone in the cell; they will thus decrease the throughput of data users, increasing thus their number.

6.5.2 Other cases

When using equipment counters only, for most systems we do not have access to the throughput achieved by each user, only average throughput information is available. When using probes or UE reported QoS (MDT or user evaluation), in addition to the equipment counters, we will be able to take into account the following information that is not available with equipment counters:

- For each user, if it is satisfied or not following a QoS target.

This allows completely defining the KPIs as described in clause 5.2.

6.6 Recommended measurement setup

A possible recommendation for the setup for measurements depends on the intended usage of the test results. In general the measurement can be done by the use of the following mechanisms:

- System provided tools - counters and event based measurement.
- Terminal reporting with MDT.
- Terminal reporting with special designed App on a Smartphone.
- Probes for application information in the core network.

The main usage of a further efficiency standard has to be agreed on and it has to be considered that it will be a tradeoff of between a simple method with limited accuracy versus a more complex method with higher accuracy. The cost for the test is also important.

The main test applications considered are:

a) to get an accurate measure of radio network energy consumption and efficiency of an existing network;

b) to help operators to know and consequently improve the EE of their networks, taking into consideration also the quality of service and experience from the served users;

c) to enable vendors to demonstrate and improve EE features under real conditions.

The three basic test methods are:

1) Testing with existing users only.

2) Test under "silent periods" with a dominating number of test users.

3) Testing with existing users and few additional test users.

The different methods have certain advantages depending on the intended application of the results as summarized in Table 1:

Table 1: Features of the different methods

	Existing users only (1)	Dominating number of test users (2)	Few test users (3)
Actual network efficiency	yes	yes	yes
Test complexity	low	high	medium
Testing time	long	short	medium
Accuracy	Depending on chosen test duration	high	Depending on ratio of existing vs. test users

Test users can be divided into standard UEs with basic reporting functionality as defined in the corresponding standard needed for network operation and those equipment with specific applications installed on the test UEs to support more detailed reporting.

The existing users in the network are recommended to be measured by the following methods:

1) Throughput measurement with network internal mechanisms.
This is the basic mechanism to be used which might be complemented by 2) and 3) below.

2) Measurement by use of deep packet inspection with probes.
This is a rather low addition to cost and complexity of the needed measurement equipment as a core network probe has capacity to measure large areas.

3) Terminal reporting.
MDT implementation might be considered as a complement or alternative as number one above. Special Smartphone applications for measurements are easy to implement but may have limited access of data the terminal but may give added application information not provided by MDT.

7 Lab network measurements

This clause deals with benefits and drawbacks of energy efficiency measurements in laboratory networks vs. testing in a fraction of a live partial network.

7.1 Benefits and drawbacks of lab network measurements

Measuring a lab network has the advantage that the network and its parameters can be well defined and measurements are repeatable.

Extending the RBS efficiency test from the one currently specified in TS 102 706 [i.2] to an efficiency test of a test network which includes several radio base stations would allow the inclusion of additional features like handovers, the interference from neighbouring cells, fading, QoS definition, etc. and provide a more complete efficiency measure. However, such an approach has some significant problems.

Complexity of the test set-up was already a large issue during the development of TS 102 706 [i.2]. Building a test RBS cluster with 7 or more base stations would also require a large number of UEs to provide a reasonable load. In the case of a static test as described in TS 102 706 [i.2], the result would be essentially the sum of the individual RBS measurements and hence would provide no additional information. Such a network test makes only sense if dynamic features and mobility are included. Also the semi-dynamic method as described in TS 102 706 [i.2] would add only adjacent cell interference and provide little extra information.

Lab-based network level testing with multiple RBS makes only sense if at least UE mobility, fading and multipath is included. This would require a very complex multi-port fading simulator which could emulate these factors. During the previous work we discussed the usage of fading and path loss generators for the testing of a single RBS. We found out that available simulators are expensive and would cause a serious challenge for the usability of the standard. The simulator needed in a complete network environment would be considerably more expensive, and is to our knowledge currently not available.

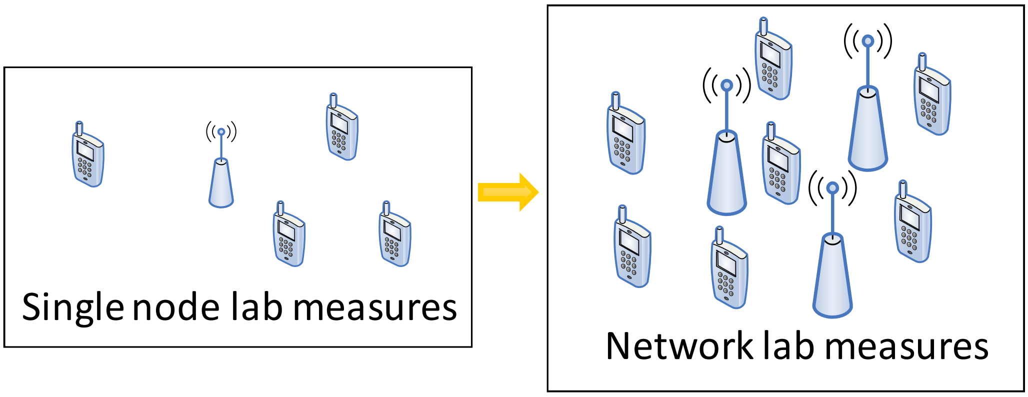


Figure 8: Lab test extension from single RBS to network

The main concern of lab testing at a network level is the extreme complexity. Besides several RBS, at least one RNC (or equivalent), a large number of user equipment, and a very complex interconnection box is required to combine the multiple RBS with the UEs.

So far, network level lab testing has been done only for very limited cases, like handover testing between two UEs. Essentially all network tests carried out by equipment manufacturers are done using outdoor trial networks. While these networks are not for public use and allow certain restrictions and a well-controlled network setup, the results are still dependent on the local conditions such as geography, buildings and their structures, etc.

7.2 Alternative solution: live sub-network measurements

Measuring in an active network (OEM test network or active operator network) has the advantage that the network is active and loaded. Little extra equipment is needed except for some power measurement and data collection equipment.

All real life factors like fading, interference, noise, multipath, etc. are present. No specific use pattern has to be defined as the network is populated, however, a certain measurement time (more than 1 day) is required to cover seasonal variances. The results from such measurements present actual energy consumption, load and efficiency figures.

The main problems related to live network testing are:

- OEM test network: Manufacturer networks are often tied to the location of the corresponding research facilities and are usually not comparable from one OEM to the other. Also environmental conditions might vary significantly.
- Operator network: An operator network covers usually a wide variety of different environments, from dense urban to scarcely populated rural areas. The main challenge is to identify a part of the overall network which can be considered as representative.

Live network efficiency measurements have significant benefits for network benchmarking of different operators. GSMA analysed with their MEE methodology a large number of mobile telecom operators. Such a complete network evaluation has to rely on often relatively inaccurate data especially for power consumption. But once accurate network energy data has been collected, operators are able to identify and implement network energy and GHG emission reduction solutions. One practical example is a recent project which identified annual use stage emission reductions of 4 kt CO^2 equivalent in one mobile network and €1,8 million annual energy cost savings with a payback time of less than three years.

An alternative solution to total network measurements is sub-network testing. Measuring in a part of an active operator network has the advantage that the network is available and loaded. Relative little extra equipment is needed to get very accurate real life data, and also factors related to the site installation and environment would be included. Life network testing could be enhanced with the inclusion of a specific load where test users are added to the network during different load phases of the network.

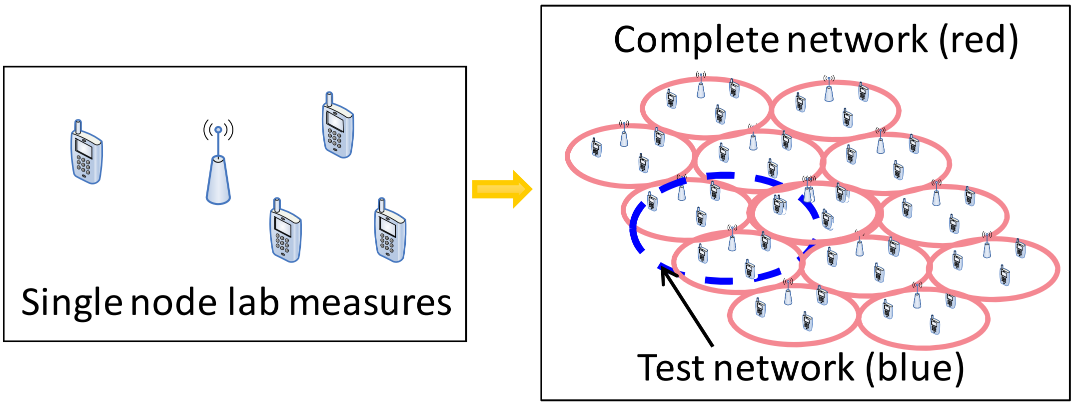


Figure 9: Lab test extension to partial live network testing

Such a test could be suitable to demonstrate efficiency improvements of SW or HW features and a reasonable accuracy under practical conditions is deemed to be achievable.

Sub-network measurements have their limitations for comparison purposes. Different classes of test networks have to be defined, like urban, suburban and rural (including certain population density ranges, geography, building structure and user behaviour. A network consists often of equipment from different generations or even different vendors. However, because of its limited size sub-network testing allows the installation of power measurement equipment and the collection of specific and precise data. With the help of a well-defined process and by a proper selection of the sub-networks valid comparisons of different equipment and even network solutions (like comparing a macro solution with a heterogeneous network) would be possible.

The measured data could be further used to extrapolate to the complete network of an operator. This would result in a methodology similar to the one from GSMA but based on more specific input parameters. Characterization of country wide networks is not in the main scope of the present document and might be considered in a later WI.

7.3 Summary

Operator sub-network tests:

- allows EE testing under real conditions;
- allows measurement of certain HW of SW features for EE improvement;
- requires classification of network environment characteristics if used for network comparison.

Laboratory network tests:

- complex and expensive;
- several test networks needed for different topologies (macro/micro, CRAN, HetNet);
- no practical use beyond academic research;

- no need to be standardized.

8 Extension to global scale

A possible straightforward usage of the metrics and the related methods to measure them in real networks is to consider the partial network measures as building blocks for the estimation of the energy efficiency of global networks.

In order to do that, the suggested procedure is the one based on "extrapolation", namely to collect measurements in as many partial networks as possible and deemed appropriate and from these partial networks "sample" measurements extend the estimation to the global network. With the term "global", as it was introduced in the scope of the present document, it is intended a wide network, possibly corresponding to the network of an operator or to the network in a country or to any network built by a multiplicity of partial networks with peculiar features.

The same approach of extrapolation is the one commonly followed when assessing the percentage of coverage of a network in a country by an operator; this assessment is made by identifying peculiar partial areas where coverage is measured and extending results to global areas by knowing in which ratio each partial area is present in the global network and multiplying by this ratio the partial results to achieve the global ones.

8.1 Scenario definition

The scenario definition is related to where the measurements indicated in clause 6 should be performed, corresponding to different network layouts that may be encountered in current radio access networks. Each "scenario" corresponds to the partial network definition that is the main scope of the present document, in the sense that in each of these scenarios a partial network measurement should take place in order to have an indication of the network efficiency per scenario.

Currently the scenario definition is particularly common in system simulations set-ups. The scenarios in the simulations set-ups are used as an emulation of real networks most usual features, depending on geography, society, traffic and so on.

Since the report main goal is about measurements it is not necessary to simulate what is already in place, but it is nevertheless important to introduce a classification of different typical areas where the measurements should be done in order to have an as complete as possible vision of a real complete network composition.

The classification criterion is mostly based on number of users or traffic offered by users in the partial network where the test is done. Hence, the scenario definition should follow the same criterion and be based on different traffic areas classification. In particular the following areas are considered (note that this definition is widely derived also from the studies performed in EARTH project, see annex B):

- *Dense urban*, with up to or more than 3 000 users per square km area on average;
- *Urban*, with about 1 000 users per square km area on average;
- *Suburban*, with about 500 users per square km area on average;
- *Rural*, with about 100 users per square km area on average;
- *Sparsely populated/wilderness*, with about or less than 25 users per square km area on average (note that this scenario is generally dropped out, here it is reported to follow the reference to the EARTH project (see annex B), but its inclusion could be further discussed).

For each of the scenarios reported above different traffic load profiles have to be defined, aiming to emulate the different conditions in which the network could happen to be operated. These load levels are generally different depending on the RAN, the country and the operators' policies. In the present document they are defined as low, medium and high traffic profiles.

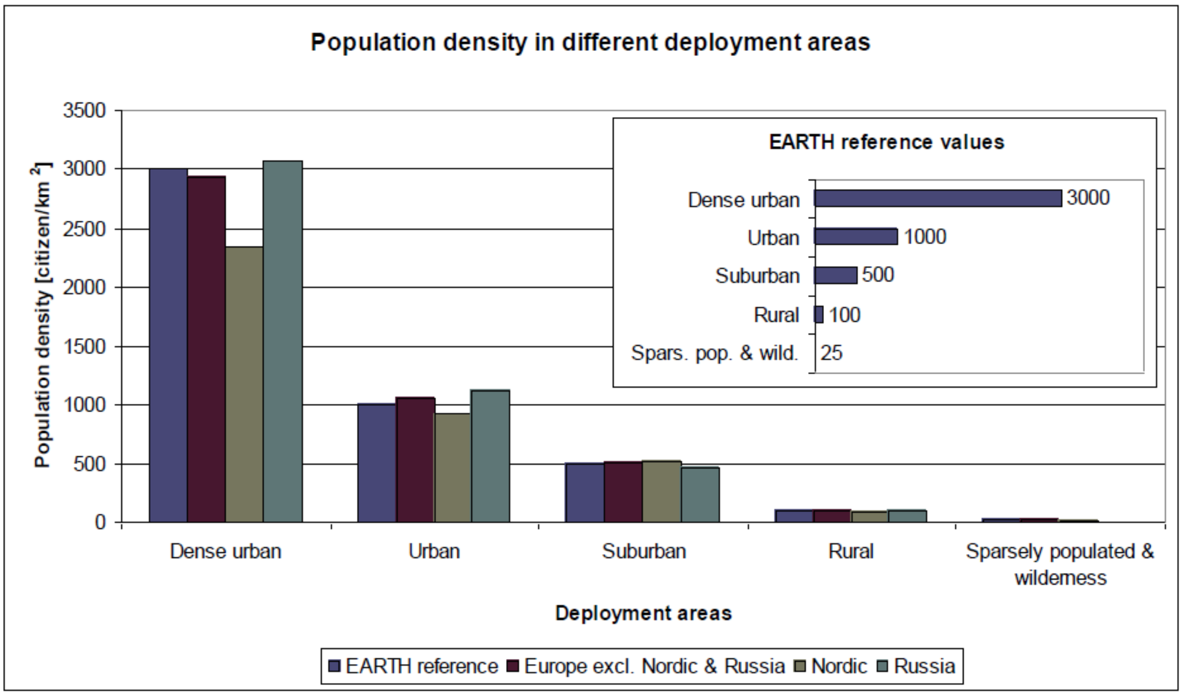


Figure 10: Population density in different deployment areas (according to EARTH project)

8.2 Ratio of different scenarios in an example network

In general a test should be performed in each of the above mentioned scenarios, identifying in the global network under investigation where they can occur. Some additional points worth considering:

- different RANs could be used in different geographical/sociological scenarios and hence not all of the above mentioned scenarios have to be tested; consider as an example LTE networks, that will be, at least in a first phase, concentrated in high traffic areas: in such a case the scenarios to be taken into consideration would be most likely the dense urban and urban, disregarding the others;
- if the global network is the one corresponding to a country, then sociological data on the percentage of presence of the different scenarios (see below) in the country could be applied directly; otherwise if the global network will be the one of a single operator some additional constraints will have to be considered (market share of the operator in the country global scenario, presence of the operator in some scenarios only, etc.).

Generally, the test results from the scenarios defined above can be extended to the global network, using an area where the presence of each scenario (as a percentage of the whole network) is known. As an example, data for Europe (taken from EARTH project deliverable D2.3 [i.10]) are available.

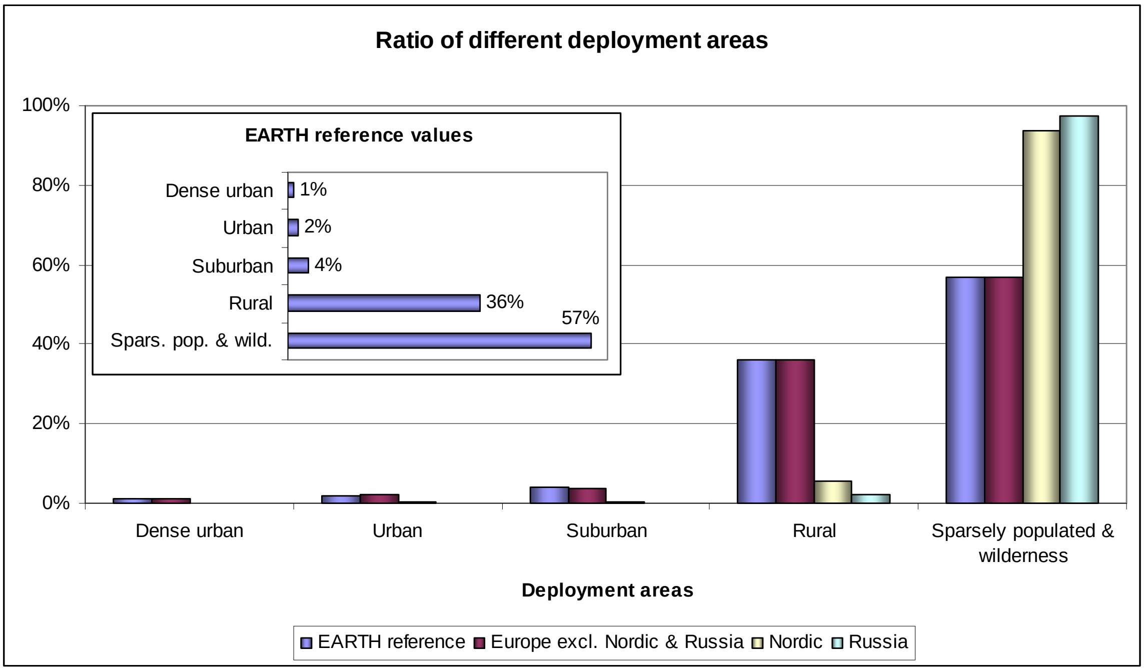


Figure 11: Ratio of different deployment areas (according to the EARTH Project)

Notice that the figures reported in the figure above (and in general any other possible sources) are to be considered just as examples at this stage; depending on the area and on the final goal of the test different figures could be used.

8.3 Example of extrapolation

In this clause, example measurements from the five scenarios introduced above are presented. These example measurements consist of different load levels (low, medium, high), with the resulting metrics based on throughput/kW. The following table presents an example for LTE technology and metrics based on Mbps/kW; the numbers are merely indicative and partially taken from EARTH deliverable D3.2 [i.10].

Table 2: Example of metrics for LTE (indicative)

Metric [Mbps/kW] Scenario	Load level	Low load	Medium load	High load
Dense urban		0,2	1	2
Urban		0,25	3	6
Suburban		0,3	5	10
Rural		0,6	10	20
Sparsely populated / wilderness		1,2	20	40

From Table 2 an extrapolation can be done considering the percentage of occurrence of the different scenarios in the network under test. As an example, consider a network where the different scenarios occur as reported in the previous clause for Europe. The final outcome will be the table reported below (the figures have been computed considering those in Table 2, weighted by the percentage of occurrence in previous clause, emulating then a network spanning the whole Europe).

Table 3: Weighted metrics with scenario average (indicative)

	Low load	Medium load	High load
Network efficiency [Mbps/kW]	0,92	15,27	30,54

Note that this is only an example, reported only for clarification purposes and not intended to represent an exact estimation of the Europe network efficiency. Moreover, it is limited to LTE only and with figures to be confirmed by exact measurements and tests. Note also that in this estimation the throughput is the overall throughput, without including any QoS/QoE effects.

A final and further extrapolation can be based on the occurrence of the low, medium and high traffic load conditions in the network under test. In particular, in TS 102 706 [i.2] it has been specified that low load conditions are in the network for 6 hours a day, medium for 10 and high for 8 hours a day. In such a case, for the above mentioned example the overall network efficiency will be about 16,77 Mbps/kW. Consider anyway that the above used approximations of traffic profile are to be further investigated for the different scenarios, possibly leading to different conclusions.

Table 4: Final average with possible example of load distribution over a day (indicative)

	Daily average
Network efficiency [Mbps/kW]	16,77

9 Recommendations for future work

In the present document a widespread view of the Radio Access network measurements have been given, focusing on the defined partial networks set-up and introducing a method to extend the validity of the partial networks results to wider environments, up to a complete operator or national network. This approach can represent the basis for further detailed assessment procedures leading to a Technical Specification about wireless network energy efficiency assessment.

The scope of the present document has led to identify live networks as the main objective to perform measurements, assigning a lower priority to other network level measurements such as those that could be performed in laboratory environment or in dedicated test trials. These tests are left to the implementation deemed as most appropriate and they will not be objective of possible future standardization phases.

Within the framework of live networks tests an essential role is played by the metrics that are to be evaluated in the tests. The choice made in the present document is particularly based on the Quality of Service/ Quality of Experience, that are essential parameters to be taken into consideration for the users' satisfaction. In order to be considered fair, a metric should include as a positive outcome of the energy spent to run a live network only results that are functional to the users' satisfaction. This principle should be further analyzed and studied in case of development of a TS, being a distinctive achievement of the present document also with respect to other initiatives in this field.

The adoption of QoS/QoE in the tests for live network energy efficiency has a significant impact also in the test methodology; many alternatives (probes, counters, MDT, and so on) have been presented in the present document, but a choice should be done in future phases in order to come to a well-defined measurement method in case of a TS.

Finally, in the so-called "extrapolation" phase towards "global" networks energy efficiency assessment, some assumptions have been made in the example presented in the present document. Accurate figures, coming mainly from sociological inspection, have to be defined together with more detailed measurement processes (observation time definition, observation time repetition, network load definitions, etc.).

In Table 5 a summary of the recommendations from the present document is given, stating where the recommendation is dealt with in the main body and what is the status of the recommendation so far.

Table 5: Summary of the recommendations in the present document

Recommendation	Where
To consider small parts of a network ("partial networks") as the building blocks for further studies in more extended networks ("global networks")	Clause 1 ("Scope") and Clause 4 ("Definition of the network in the scope"), especially Figure 1
To narrow the work to GSM, UMTS and LTE	Clause 4 ("Definition of the network in the scope")
To introduce QoS or QoE in the network energy efficiency metrics	Clause 5 ("Metrics and data for network level energy efficiency") and especially clause 5.2
To introduce a procedure (four phases) to test energy efficiency in radio access networks	Clause 6.1
To exclude lab measurements from the scope	Clause 7 ("7 Lab network measurements")
To develop a method to extrapolate global network efficiency from partial networks measurements	Clause 8 ("8 Extension to global scale")

There are some aspects in setting up an energy efficiency test of a network that have impact that would need further analysis to be addressed in a possible technical specification, including:

- selection of terminals to be used in the test set-up;
- use of MDT in terminals;
- use of MDT with support of additional App in the terminal;
- use of dedicated terminals;
- make separate recommendations for different RATs (GSM, WCDMA and LTE);
- the impact of work-load with dedicated terminals, in case test users will be the selected alternative to make measurements;
- collection of data from the measurements and further post-processing of data;
- handling of data confidentiality and related non-disclosure procedures (even if the objective of any possible specification will be a method, independent from the confidentiality of data).

Annex A: OPERA-Net

A.1 The OPERA-net project

OPERA-net is a Celtic project within the EUREKA framework. The OPERA-Net project (Optimising Power Efficiency in mobile Radio Networks) aimed to develop a holistic approach considering modelling of a complete end-to-end system for the 2G and 3G+ radio access technologies, identifying all relevant network elements and their interdependencies. It was one of the very first international projects focusing on energy efficiency of telecom networks. The members of the first project (June 2008 to May 2011) were France Telecom / Orange (project leader), Nokia Siemens Networks, Alcatel-Lucent, Freescale, Thomson, EFORE, MITRA, IMEC, Cardiff University and VTT.

The OPERA-net activity is continuing in the OPERA2 project, which has started in December 2012 and will continue until November 2014. The goal of OPERA2 is to support the standardization effort on energy efficiency assessment of wireless networks.

Results from OPERA-net include:

- Cell size breathing scenarios - possible sleep/low power modes for base station.
- Network load dependent reconfiguration.
- Dynamic service management and traffic handling (traffic balancing between air interfaces).

Prior related research within academia and the wireless network industry was highly fragmented and tended to focus on improving and optimizing individual subsystems in isolation. In contrast, the OPERA-Net project considers a complete end-to-end system, identifying all relevant network elements and their interdependencies (Figure A.1).

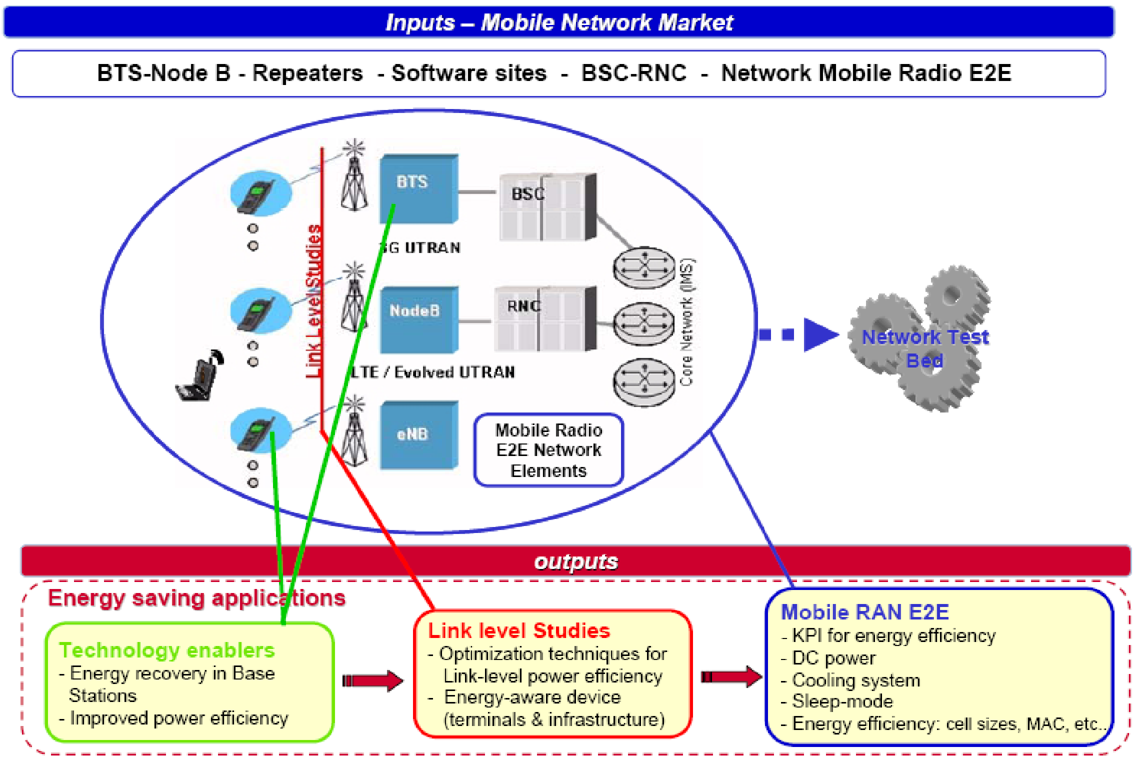


Figure A.1: OPERA-Net approve from analysing component energy efficiency to complete E2E efficiency

The project was organized in 6 work packages. Work package 1 was assigned to project management and work package 6 to dissemination of results including contributions to standardization bodies. As OPERA-Net is no member of organization like ETSI or ITU, the result were submitted by the participating companies. The four technical work packages covered mobile RAN E2E efficiency, link level studies, technology enablers and test beds.

The project results cover a wide range of radio network details: an analysis of power consumption and associated CO2 emissions of different segments of global mobile networks (Figure A.2), a model for radio base station power consumption (described in more detail further down) which was used within the project to include power consumption calculations in network planning and performance calculation tools. This allowed for the first time to directly calculate power consumption and the impact of different upgrade solutions when planning a radio network. However, OPERA-Net analyzed not only potential saving methods but focused on solutions and their application in already existing networks. This included in particular the impact of sleep modes on network performance and quality of service. Sleep mode activation and deactivation methods were developed and tested. One of the key challenge with sleep modes is the fact that if the deactivation threshold is high, it saves more energy but at the same time degrades QoS. Some results are outlined in Figure A.3.

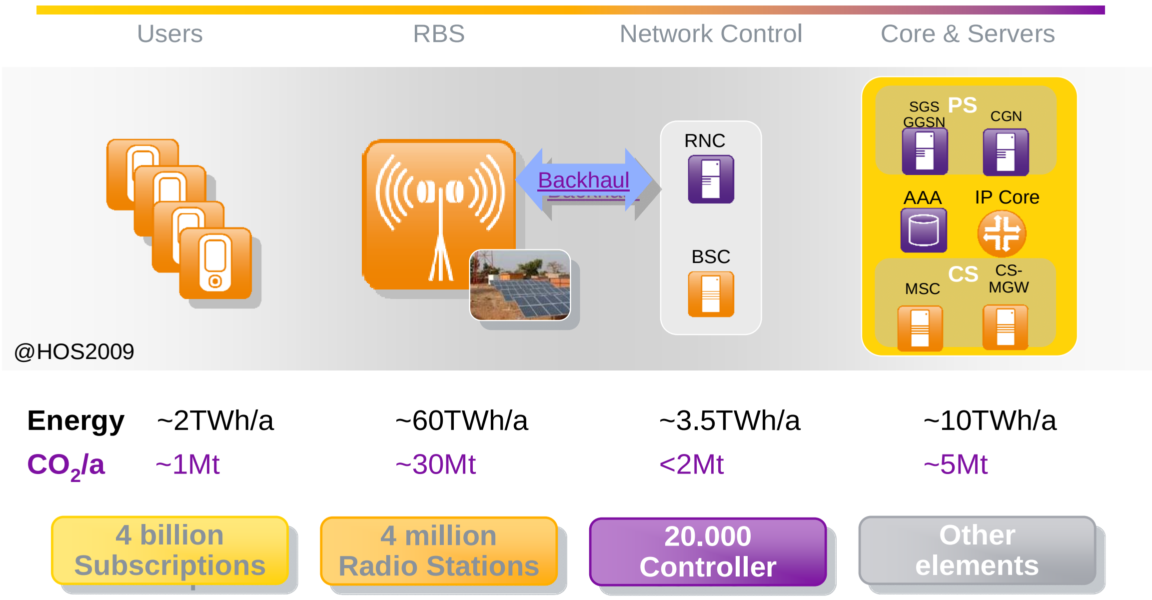


Figure A.2: Global mobile network energy consumption and related CO2 emissions (2008)

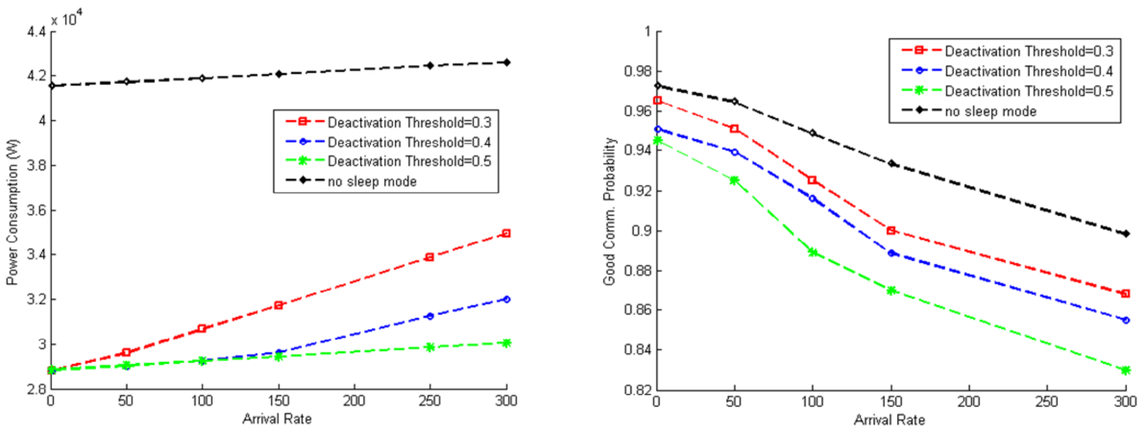
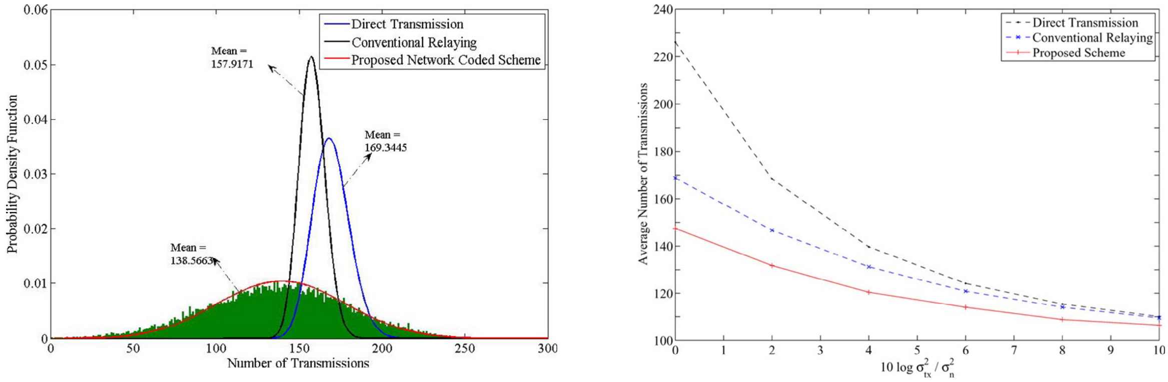


Figure A.3: Impact of sleep mode threshold on energy saving

Link level analysis were carried out to analyze the impact of different coding and decoding algorithm on E2E efficiency like link level assessment of a new optimisation strategy for joint channel and network coding (JCNC) scheme, the overall energy to achieve target QoS levels are evaluated and compared for different transmission cases. A total energy savings of 33 % at a target PER of 10^{-4} can be achieved using our proposed scheme compared to the conventional methods.

The analysis of cooperative networks demonstrated further efficiency improvements. The application of fountain codes in cooperative relay networks has been analysed. The source transmits partial information about the next message already during the current block transmission, thereby expediting the transmissions of subsequent blocks. The proposed scheme requires less number of transmissions and saves this way energy (Figure A.4).



PDF of required number of transmissions   Average number of transmissions in fading channels

Figure A.4: Energy saving in cooperative networks by reducing number of required transmissions in fading channels

OPERA-Net 4 analyzed also enabling hardware technologies in particular power amplifiers for mobile radio and television base stations. Cellular base stations operate currently on a relative narrow band while TV transmitters have to cover a much wider frequency range. The impact of different power amplifier solutions Figure A.5) have been analyzed and compared. While peak power efficiency is approaching its physical limit, significant efficiency improvements can be achieved at low load levels.

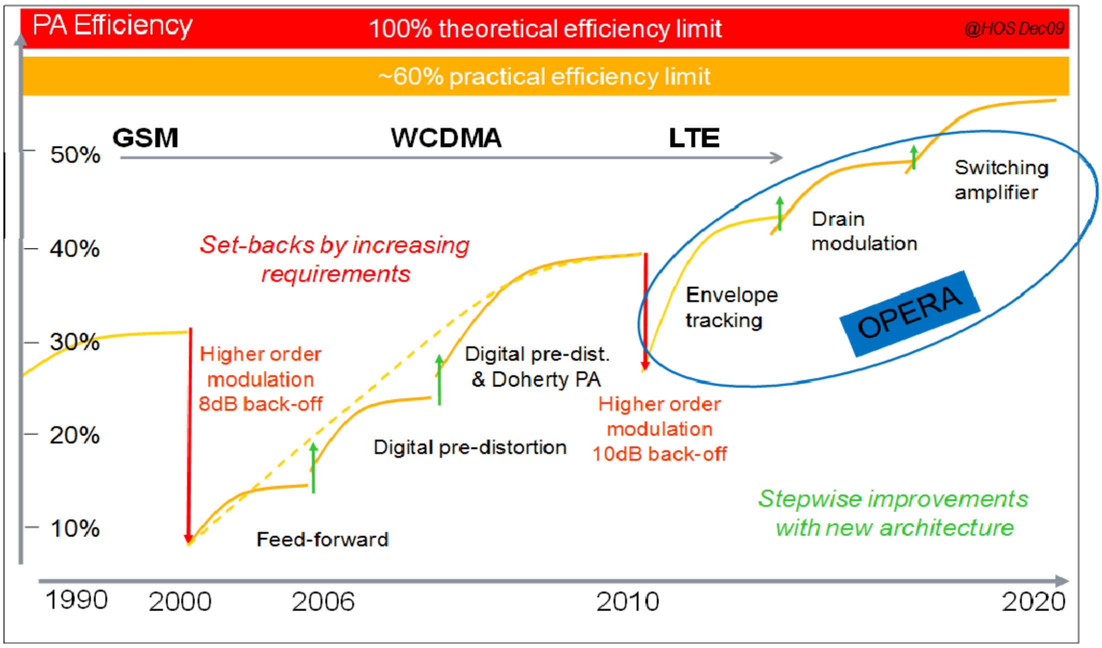


Figure A.5: OPERA-Net work area on RF power amplifiers

Power amplifiers are traditionally judged by their peak power efficiency. One of the main challenge in cellular networks is to provide sufficient capacity at peak load levels but to operate efficiently most of the time at considerably lower load. The new power amplifiers which will improve efficiency at lower load (Figure A.6) will support this target.

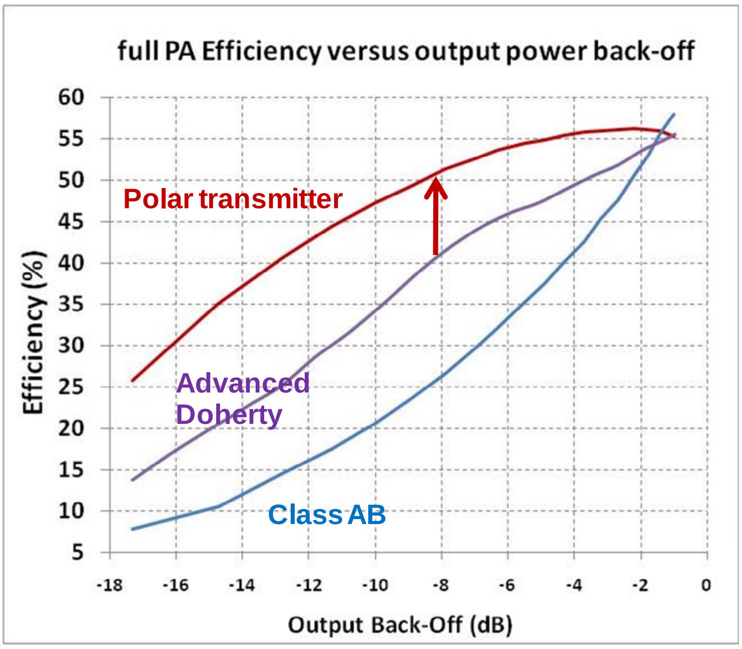


Figure A.6: Power amplifier efficiency at different load levels

A.1.1 The OPERA-Net base station power model

Starting from a generic BTS block diagram the most relevant elements and their dependency on installed capacity and actual load is described. A general BTS model is created and some basic parameters are proposed for demonstration purposes.

A.1.1.1 Description of macro base station sites

The macro BTS site installation can be separated into two main units, site support and BTS (Figure A.7).

A.1.1.2 Site support system

The site support system is the interface between the energy supply (typically 230V mains) and supplies the BTS with the standard 48V DC, but includes although power back-up and air conditioning. A site might contain additionally a Diesel generator set.

The site support is a very location or environment sensitive item. Therefore, site support and related power consumption is omitted in the BTS model.

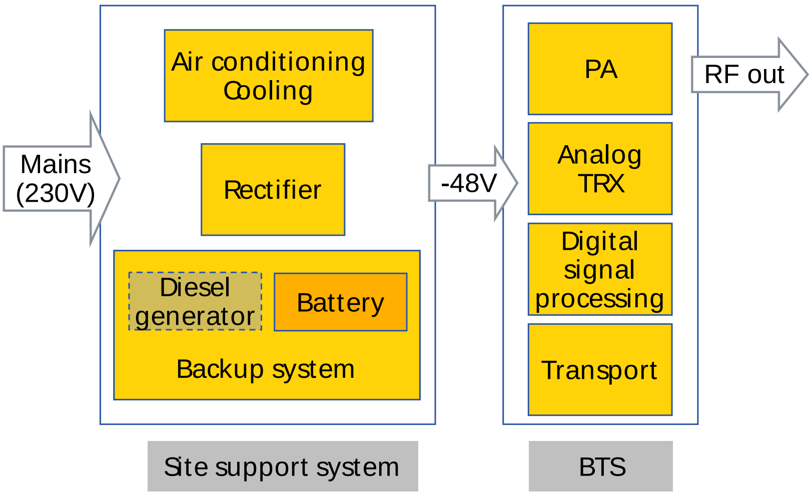


Figure A.7: Macro site block diagram

A.1.1.3 Radio Base Station

A BTS and the resulting power consumption can be split into the following blocks:

$$P_{IN} = \eta_R * P_{BTS} = \eta_R * (P_T + P_{DSP} + P_{TRX} + P_0 + k_{PA} * P_{out})$$

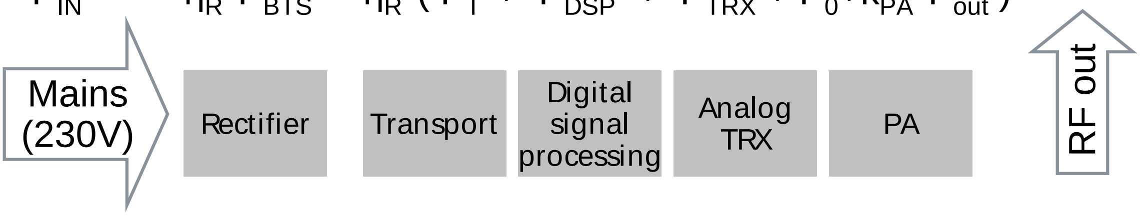


Figure A.8: Main blocks in a BTS for power consumption estimation

a) Transport - Point of the lowest data rate, therefore relative low power consumption and typically load independent.

b) Digital signal processing - Combined digital functions for system processing, coding, waveform generation, etc. Digital signal processing can consume a considerable fraction of the overall BTS power. Currently, power consumption of the digital part is mostly load independent. The increasing demand for improved energy efficiency will most likely lead to load dependent solutions in the future.

c) The Transceivers (TRX) - A transceiver covers mostly the analogue signal generation, signal conversion, amplification, filtering, etc. but includes to a certain extent also digital functions. The TRX power consumption is slightly load sensitive.

d) The power amplifier - The PA stands for the largest part of the consumed BTS power, at least in the case of a macro BTS. The power consumption of the PA is load dependent.

As can be seen already from above simple BTS model, there are several implementation dependent factors determining the power consumption of a BTS. A generally valid equation describing precisely base station power consumption would require a dedicated set of parameters for each configuration and hence, be meaningless. However, it can be also seen that there are several generic power dependencies of a BTS. The target is to develop a model describing these dependencies. Based on this we can simulate the power consumption of a complete network with different configurations. The result might be used as guidance for network optimization as well as for the design of future BTS modules and configurations.

As Figure A.8 shows, there is basically a load independent power consumption component from transport, base-band/DSP, TRX and the power amplifier. On top of this fixed part, there is also a load dependent part mostly generated by the power amplifier and some smaller contribution from the rectifier.

Cooling was separated from the BTS model above and combined in a single cooling element under site support. In praxis we might have some fans included in the BTS directly. Cooling is of course load dependent, but also an environmental factor. The amount of power consumed by the fans is relatively small, future BTS might even work completely with passive cooling. Air conditioning on the other hand can contribute to a large amount of additional power consumption in certain countries. As long as our target is to find the macro network configuration with the lowest energy consumption under the same environmental conditions we can neglect cooling. Only if we want to determine the exact energy consumption of a particular network in a certain environment the additional cooling energy has to be included.

Based on above considerations the following, simple BTS model could be created:

$$P_{BTS} = P_0 + k{*}P_{load}$$

Load factor: $k = 0{,}1 \ldots 1$

Figure A.9: Simple BTS power model

The load factor k is assumed to vary from ~0,1 (10 % load, broadcast channels only) to 1 (100 % load). The power factors P0 and Pload depend on the actual configuration, capacity and implementation and will be selected based on empirical results.

The disadvantage of above model is that the factors do not describe different site configurations. It is also difficult to take different configurations, like the impact of baseband capacity or total installed RF power easily into account. New coefficients have to be calculated for every BTS configuration.

A.1.1.4 The BTS power consumption model

The following shows a more complex model taking different site configurations into account. The constant power factor is separated into a processing and a radio part, and the load dependent part is separated into a factor describing the number of antenna sectors and the installed RF power.

$$P_{BTS} = n{*}P_P + m{*}(P_{TRX} + k{*}P_{RF}/c)$$

Load factor: $k = 0{,}1 \ldots 1$

BB capacity: n = installed processing capacity increment

RF capacity: m = installed antenna sectors

RF conversion: c = conversion factor for RF_{out} to DC_{IN}

Figure A.10: Complex BTS power model

The elements of the new model are defined as following:

k: load factor, describes the fraction of installed RF power which is actually transmitted. For any active sector k cannot reach the value zero. The minimum is defined by the need for the broadcast channel power. For WCDMA a value of 0,1 is often used. However, this depends on the actual network deployment and is not a fixed value.

n: increment of installed baseband processing capacity. Typically, a BTS module or sub-unit has a certain capacity (for example 240 channel elements). If higher capacity is required additional units have to be installed. "n" is therefore an integer, typical values are 1 to 3, but higher values are possible for extreme large BTS configurations.

m: number of installed sectors.

P_P: power consumption of the digital processing unit

P_{TRX}: fixed power consumption of the radio module

P_{RF}: maximum RF output power of the PA

c: DC to RF conversion factor. This factor is largely dependent on the PA efficiency but by no means a direct measure for PA efficiency.

Not all sectors need to have the same load factor, see also clause "BTS model variation for independent sector load".

A.1.1.5 BTS model variation for independent sector load

The above model assumes an equal load for all BTS sectors. In many cases it might be interesting to include the effect of different loads on each sector. For this purpose the model could be simply expanded to:

$$P_{BTS} = n*P_P + m*P_{TRX} + (k_1+\ldots k_n)*P_{RF}/c$$

The installed maximum RF power (PRF) is typically equal for all sectors as we usually install the same H/W for all sectors. However, future BTS might apply PA with programmable maximum output power. In this case different sectors might operate with different output power. In this case the equation could be modified as following:

$$P_{BTS} = n*P_P + m*P_{TRX} + (k_1*P_{RF1}+\ldots k_n*P_{RFn})/c$$

Typical values for P_{RF} are 20W, 40W and 60W. Values for k_i are as before: $\sim 0,1 < k_i \leq 1$

A.1.1.6 Ideal BTS model

The power consumption of an ideal RBS follows the actual load. Unfortunately, the power consumption of current RBS is only weakly correlated with the load. The degree of adaptation can be expressed by the following formula, where the RBS power consumption is proportional to the load for an adaptation factor $\alpha = 1$, while $\alpha = 0$ represents an RBS with load independent power consumption.

$$\alpha = 2 \cdot \left(1 - \int_0^1 P_{rel}(L_{rel}) dL_{rel} \right)$$

$P_{rel}(L_{rel}) = P(L_{rel}) / P_{max}$

$P(L_{rel})$: power consumption depending on load [W]
P_{max}: power consumption at max. load [W]

After we defined the RBS adaptation factor, the RBS model can be also written as:

$$P_{RBS} = (1-\alpha) \cdot (P_P + P_{TRX}) + \alpha \cdot k_i \cdot P_{RF} / c)$$

The number of digital baseband processing increments is now embedded in the adaptation factor α. The preferred annotation depends on the application.

Annex B: Earth project

The EARTH research project [i.8] is a concerted effort with 15 partners from industry, SME and academia (Figure B.1) addressing improvements of the energy efficiency of mobile communications infrastructure. The overall goal is to derive solutions that together in an Integrated Solution will decrease the energy consumption by 50 %, without degrading quality of service. EARTH committed to complement its theoretical studies with trustworthy proof-of-concepts for the individual solutions, as well as for the overall integrated solution. The ultimate goal is to enable sustainable growth for the Future Internet.

The EARTH project started in January 2010 and received funding as an FP7 IP project from the European Commission under FP7 ICT Objective 1.1 "The Network of the Future" under Contract Number INFSO-ICT-247733. The project was successfully completed in June 2012.

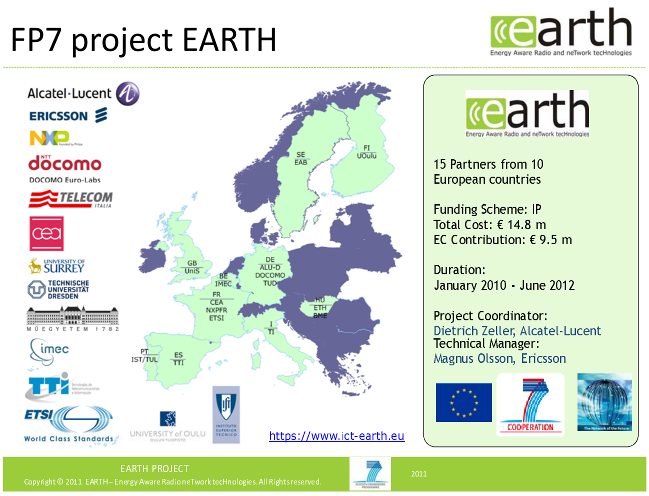


Figure B.1: EARTH consortium and funding

B.1 EARTH Major Results

The access to the Future Internet will be dominated by wireless devices. The resulting explosive traffic growth challenges the sustainability of mobile networks. EARTH (for project scope and structure see Figure B.2) provides a framework for assessing the energy consumption and energy efficiency of the wireless access networks, identifies saving strategies and quantifies the potential energy saving of four integrated solutions tailored for different traffic scenarios [i.9], [i.10].

- EARTH analysed for the first time the impact of Future Internet on sustainability and energy demands of mobile communications infrastructure. It showed that the EARTH Integrated Solution, yielding > 50 % savings, allows avoiding an increase of CO_2 emissions and energy demands, whilst expanding the mobile communications infrastructure to satisfy future traffic demands.

- EARTH developed key solutions for improved energy efficiency of such infrastructure and analysed their merits. The solutions act all the way, from more efficient components in the radio base stations, up to solutions on the radio network level. The scenarios and context under which these solutions are providing savings are very different. Some solutions provide gains at high traffic loads, whilst at low loads they are detrimental. Others bring in their merits especially at low to medium loads. Also, the savings on network level depend very much on the actual context in which a solution is used.

- EARTH developed the methodology 'E3F' for the evaluation of such gains on network level. It allows assessing which gains a solution or a combination of solutions yield in realistic scenarios of real networks, and allows for an objective and fair comparison of different concepts. This methodology has applications far beyond EARTH, being also adopted outside the project in other research initiatives, and provides a foundation for standardising the characterisation of network energy efficiency in ETSI Eco-Environmental Product Standards.

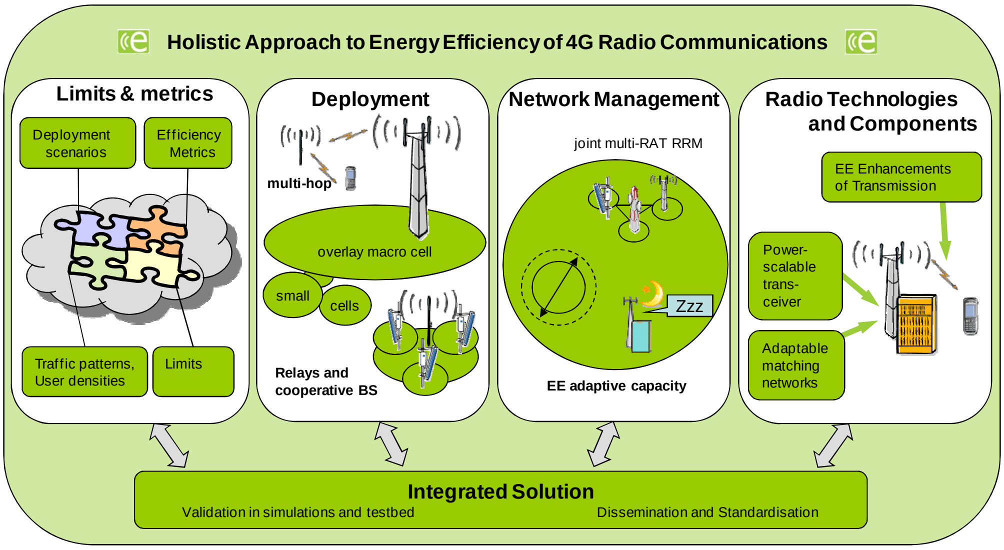


Figure B.2: EARTH WP structure [i.8]

B.1.1 Description of the model

EARTH is using system level simulations of network nodes, components and important building blocks in order to evaluate EE on network level [i.11], [i.12]. Within the EARTH project the state-of-the-art system simulation approach (e.g. from TR 36.814 [i.17] and ITU M.2135 [i.19]) has been extended from performance metrics to energy efficiency metrics. However, it is not feasible to simulate large-scale deployments. Therefore, the EARTH model is evaluating well defined reference scenarios (snapshots) and aggregates the result over 24 hours and over different deployment areas of a country into a representative country-scale operator network (Figure B.3).

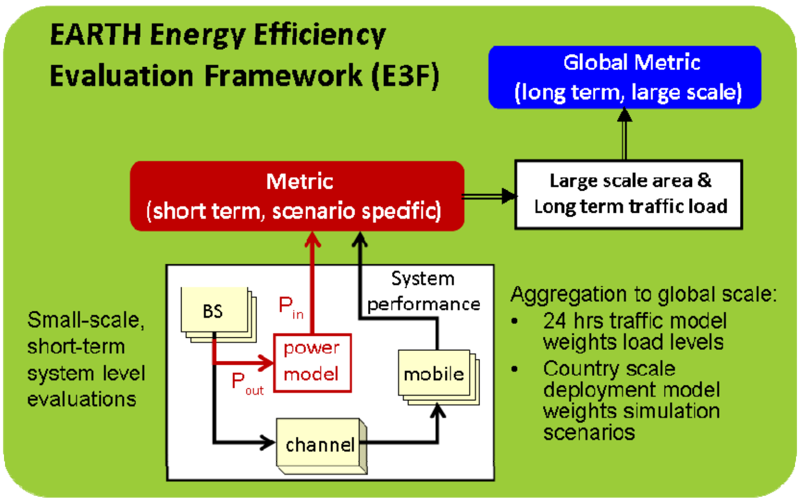


Figure B.3: EARTH Energy Efficiency Evaluation Framework

The EARTH framework is specifying the system parameter in several sub models for small-scale and large-scale simulation. Figure B.4 explains how the sub models enter into the framework.

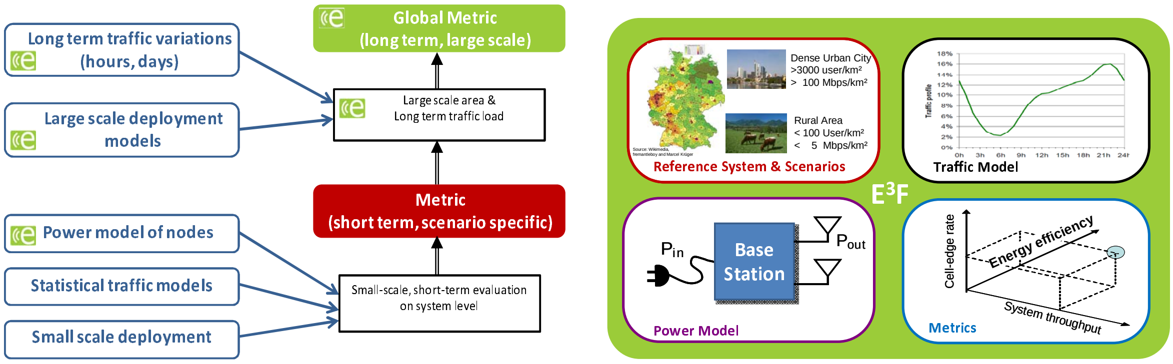


Figure B.4: Modelled input for the EARTH Energy Efficiency Evaluation Framework

The underlying radio link model consists of all transmitter-to-receiver links in the network between the base station and the UE or mobile. This includes both direct radio links and interference between adjacent cells as well as fading. The channel has distance dependent path-loss, wall penetration losses and in the case of MIMO parallel paths are generated between each transmit and receive antenna element. The parameters of the channel model are chosen according to TR 36.814 [i.17].

Deployment scenarios specify different subscriber densities (dense urban, urban, suburban, rural areas and scarcely populated areas). Figure B.5 illustrates this, see clause 8 for the specified values. Reference deployments with 57 cell hexagonal layout are defined with typical inter site distances (e.g. 500 m or 1 732 m) and mobility speeds (3 km/h, 30 km/h, 120 km/h) according to the areas. The scenarios considered by EARTH are based on 3GPP scenarios, but these can without loss of generality be replaced by other scenarios.

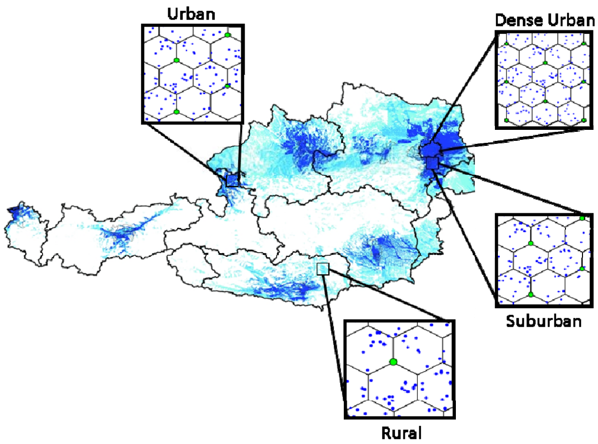


Figure B.5: Example of deployment areas with different BS and user densities

Power models for 4 different BS classes (macro, micro, pico and femto BSs) map the consumed input power Pin to achieve a certain RF output power Pout at the antenna. The power consumption regards all BS components and support systems (Figure B.6). The power model is built from detailed analysis of the load dependency of hardware components and computation complexity [i.13].

$$P_{\text{in}} = N_{\text{TRX}} \cdot \frac{\dfrac{P_{\text{out}}}{\eta_{\text{PA}} \cdot (1-\sigma_{\text{feed}})} + P_{\text{RF}} + P_{\text{BB}}}{(1-\sigma_{\text{DC}})(1-\sigma_{\text{MS}})(1-\sigma_{\text{cool}})}$$

where P_{in} is the total consumed electrical power and P_{out} is the transmitted RF power. The coefficients η_{PA} for the PA efficiency, σ for the loss factor of power conversion and cooling, and the power consumption P_{RF} and P_{BB} of RF and base band processing depend on the load level, i.e. on P_{out} /. $P_{out,max}$. However, the final model may be simplified by a linear approximation [i.14].

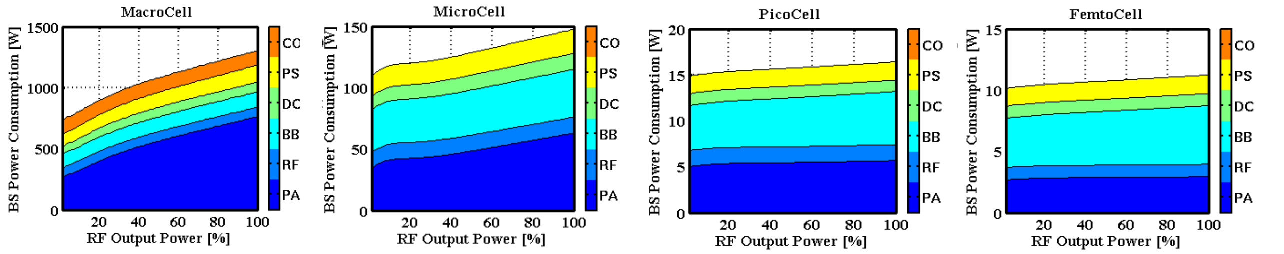


Figure B.6: Power modles for 4 BS classes, with breakdown to the BS components

User traffic demand for each small-scale simulation is specified based on user activities on different device types k (PCs, tablets, smartphones, feature phones) and over a day.

$$R(t) = \frac{p}{N_{op}} \alpha(t) \sum_k r_k s_k$$

where R(t) is the traffic density [bps/km²], p is the population density [subscriber/km²], Nop is the number of competing operators, α(t) is the activity probability of users, rk is the service rate for a video stream on device k and sk is the ratio of users applying device type k. Further, the summation may be refined by introduction of heavy users and normal users. The resulting traffic density during busy hour (where α(t)=16 %) is given in the table in clause 8 for 3 scenarios with different fraction of heavy users. The scenario with 20 % heavy users is assumed to best describe the traffic level expected for 2015.

Finally, the large scale model specifies the weights of the different snapshots for a typical European operator network. The long term and global metric is achieved by aggregating the small-scale snapshots of the 24 hour traffic variation and country scale scenarios. The result is expressed as energy intensity, i.e. in total energy consumption per area [kW/km²] or per carried traffic [J/kbit] (see clause 8 for the specified values). Further, the power consumption per subscriber [kWh/year] is used to compute the sustainability of network power consumption for exponential traffic increase.

B.1.2 Rationale

EARTH has identified a gap in the specification of energy efficiency measurements:

- Existing standards for measurements on BS level [i.1] are suited to compare between BS hardware of different vendors. However, they cannot analyse the impact of modifications in the deployment scheme.
- Measurement of network level energy efficiency in lab environment is limited to just a few BSs and cannot mirror the scale and diversity of deployment scenarios in an operator network.
- GSMA benchmarking service [i.16] applies network level energy measurements in a real operator network (trial network or complete commercial network) and normalises the result to climate, technology differences and coverage range. This can assess the total power consumption and compare energy efficiency between operators, however it does not provide insight what the reason for higher consumption is, what part of the network is most energy hungry and where the highest potential for savings is.

Therefore, EARTH has designed the E^3F to provide a breakdown of the overall consumption and of the energy intensity in [kW/km²] over the snapshot scenarios. This provides operators with guidance where an improvement of the network yields highest impact on the large scale network.

In EARTH, E^3F is also used beyond the scope of ETSI measurement specification to assess energy efficiency in simulations. This allows anticipating the effect of new network features on network level energy efficiency for a future or planned configuration even before deployment. The saving potential of advanced network configurations, e.g. with dynamic management, BS cooperation and complex HetNets can be studied and best practise rules can be found.

The EARTH framework provides a full set of system-level simulation assumptions and network modeling for a typical European 4G operator. However, the paradigm of the EARTH framework can be adapted to any other scenario by using dedicated traffic, deployment and link models. The power model can be extended to advanced hardware or to 2G and 3G networks.

B.1.3 Domain of validity

The E^3F model assesses the energy consumption on network level from simulation or measurement of a set of representative scenarios (snapshots). The model includes the total power consumption in dependence of system load and user experience. The validity of the model obviously depends on a proper selection of scenarios and of their weights in the overall network aggregation.

EARTH has provided a complete set of parameters for power model, traffic model and system simulations, targeting the EARTH saving potential for European LTE networks in 2015. The model parameter may have to be adapted for other applications. E.g. for developing counties other fractions of rural areas may apply and for the long range beyond 2020 even higher traffic loads may occur. Another possible extension is for very highly populated inner city areas. Together with commuting people these areas can have user densities of 10 000 to 20 000 per km^2 and require much denser network deployment. For E^3F these areas have not been explicitly included because they cover only a small fraction of a country. Nevertheless, they strongly impact the user experience of a network.

B.1.4 Use case examples

The EARTH project has used the E^3F as described in clause 2 to analyse the power consumption of an European reference network, operating at 2 GHz. The breakdown of power consumption to areas in a network reveals a roughly equal impact of rural and urban areas even though rural areas are by far dominating area wise (Figure B.7).

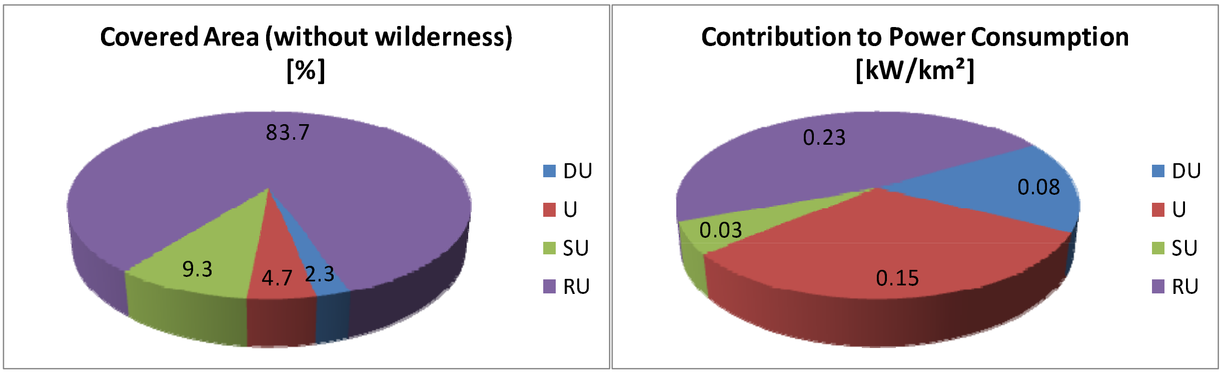


Figure B.7: E3F breakdown of areas and of power consumption of areas in a network [i.15]

The E^3F has further been applied to study the temporal behaviour of power consumption over a day and to compare different combinations of saving techniques in an integrated solution. As an example, Figure B.8 left shows the saving over the reference network (SOTA), identifying that two of the saving strategies experience a crossover at a certain traffic level, i.e. at 15:00. Figure B.8 right shows the aggregated saving potential over 24 h and over all area types with up to 70 % saving for the best combination of techniques, i.e. in this case for adaptation of bandwidth combined with micro DTX and adaptive hardware (see EARTH deliverables D3.3 and D3.4 [i.10]).

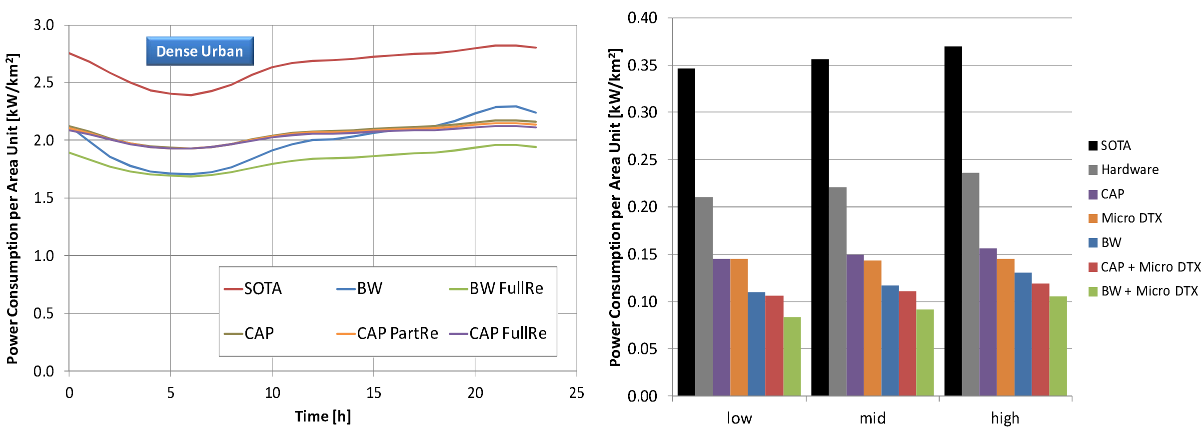


Figure B.8: Example simulation results using the EARTH Energy Efficiency Evaluation Framework

Annex C:
MDT to estimate QoS

3GPP started study at MDT (Minimization of Drive Tests) since release 9 and set WI at Rel-10 and Rel-11 respectively. The aim of MDT is to automating the collection of UE measurements to minimize the need of manual drive-tests. At TR 36.805 [i.20], it defined use cases and requirements for minimizing drive tests in next generation LTE/HSPA networks. Based on the defined use cases and requirements, it studied the necessity of defining new UE measurements logging and reporting capabilities for minimizing drive tests and analysed the impact on the UE. WI- Minimization of drive tests for E-UTRAN and UTRAN at Rel-10 defined by RP-091423 is finished at the end of 2011, Rel-10 MDT solution is based on control plane architecture with a focus on coverage optimization.

At Rel-11, a new WI "Enhancement of Minimization of Drive Tests for E-UTRAN and UTRAN" was set at RP-120277 which intends to continue the Rel-9 and Rel-10 work on defining the solutions for MDT. Besides coverage optimization, Rel-11 will also address QoS verification which has been investigated in the study item and found beneficial. For coverage optimization use case, it is related to location information and not so relevant to the data availability discussed here. For QoS verification use case, scheduled IP throughput, data volume and accessibility are identified features. Among all the features, scheduled IP throughput may be used for EE KPI calculations.

For Scheduled IP throughput:

- the objective of this measurement is to measure over Uu the IP throughput independent of traffic patterns and packet size;
- for both LTE and UMTS, scheduled IP Throughput measurements for MDT should be performed per RAB per UE and per UE;
- for LTE, the length of the measurement collection period should be configurable by OAM, and values in the order of 1 024 ms, 2 048 ms, 5 120 ms, 10 240 ms and 1 min should be supported. For UMTS, the value range for measurement collection period is 1 second to 64 seconds.

Figure C.1 illustrates an example where there are 3 RABs, [i.21]. During measurement period *n*, there are two data bursts on RAB1, one data burst on RAB2, and one data burst on RAB3. QCI *X* is associated with RAB1 and RAB2, while QCI *Y* is associated with RAB3.

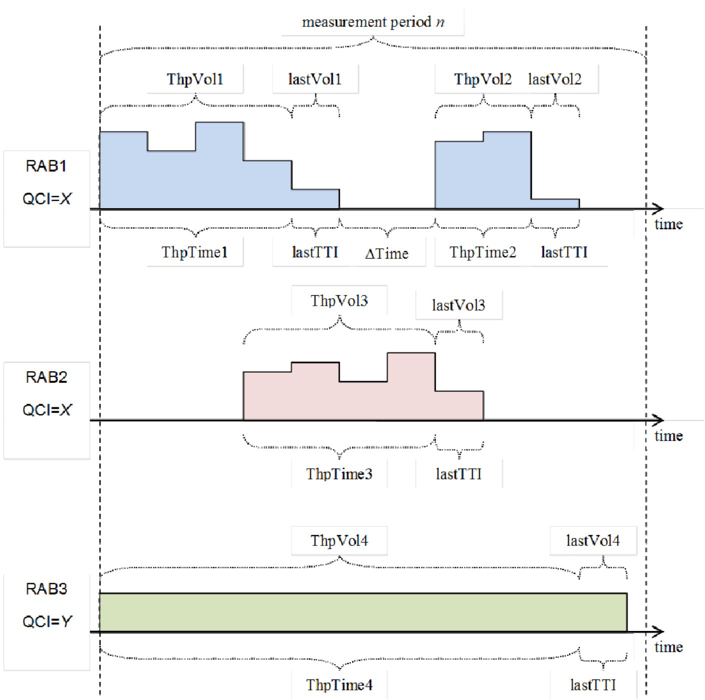


Figure C.1: Example of Scheduled IP Throughput, 3 RABs and 2 QCI

Assuming the above, the value(s) for Scheduled IP Throughput for measurement period *n* would be as follows:

- RAB-level:

$$\text{RAB1} = \frac{\text{ThpVol1} + \text{ThpVol2}}{\text{ThpTime1} + \text{ThpTime2}} \text{x}1000[kbits/s]$$

$$\text{RAB2} = \frac{\text{ThpVol3}}{\text{ThpTime3}} \text{x}1000[kbits/s]$$

$$\text{RAB3} = \frac{\text{ThpVol4}}{\text{ThpTime4}} \text{x}1000[kbits/s]$$

- UE-level:

$$\frac{(\text{ThpVol1} + \text{lastVol1}) + (\text{ThpVol2} + \text{lastVol2}) + (\text{ThpVol3} + \text{lastVol3}) + \text{ThpVol4}}{\text{ThpTime4}} \text{x}1000[kbits/s]$$

Note that a UE-level measurement sample cannot be derived from RAB-level measurement samples, except in special cases.

The RAB-level measurement will reflect user experience directly as each RAB has its own distinctive QoS requirements. The UE level Scheduled IP Throughput can be considered as a reference. The detailed definition Scheduled IP Throughput could be found at R2-124358_36314_CR0027r1_(Rel-11)_Introduction of MDT measurements for LTE [i.22] and R2-124353_37320_CR0046r1_(REL-11) for UMTS [i.23].

History

Document history		
V1.1.1	November 2012	Publication