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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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## Assessment of mobile network energy efficiency

Recommendation ITU-T L.1331

ITU-T

ITU-T L-SERIES RECOMMENDATIONS

**ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT**

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# Recommendation ITU-T L.1331

## Assessment of mobile network energy efficiency


### Summary

Recommendation ITU-T L.1331 aims to provide a better understanding of the energy efficiency of mobile networks. The focus of this Recommendation is on the metrics and methods of assessing energy efficiency in operational networks.

The networks considered are those whose size and scale could be defined by topologic, geographic or demographic boundaries.

This Recommendation explains how to extrapolate the measurements made on partial networks to the level of the total network. Such a simplified approach is proposed as a way of making approximate energy efficiency evaluations at the level of network elements, and cannot therefore be considered sufficient for the entire network operation including, for example, transport.



### History

| Edition | Recommendation | Approval | Study Group | Unique ID* |
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### Keywords

Energy efficiency, metrics, mobile, networks.


* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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## Table of Contents

## Introduction

Recommendation ITU-T L.1331 considers the definition of metrics and methods used to measure energy efficiency performance of mobile radio access networks and adopts an approach based on the measurement of such performance on small networks, for feasibility and simplicity purposes. Such a simplified approach is proposed for approximating energy efficiency evaluations and cannot be considered as a reference for planning evaluation purposes throughout the network operation process. The same approach was introduced in ETSI TR 103 117; the measurements in testing laboratories of the efficiency of the base stations is the topic treated in ETSI ES 202 706.

The measurement of this performance is useful for many reasons, and implementation guidelines are given in clause 11.

Recommendation ITU-T L.1331 also provides an extrapolation method to extend the applicability of the assessment of energy efficiency to wider networks.

The general outcome of the application of the method specified is based on the "Assessment report" introduced in clause 10. An example of an application of the method is given for better readability and ease of use in Appendix I.

Recommendation ITU-T L.1331 was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published by ITU and ETSI as Recommendation ITU-T L.1331 and ETSI Standard ETSI ES 203 228 respectively, which are technically equivalent.

# Recommendation ITU-T L.1331

## Assessment of mobile network energy efficiency

## 1 Scope

This Recommendation aims to provide a better understanding of the energy efficiency of mobile networks. The focus of this Recommendation is on metrics for energy efficiency and methods of assessing (and measuring) energy efficiency in operational networks.

This Recommendation defines the topology and level of analysis needed to assess the energy efficiency.

The analysis includes radio base stations, backhauling systems, radio controllers (RCs) and other infrastructure radio site equipment. The technologies involved are global system for mobile communication (GSM), universal mobile telecommunications service (UMTS) and long term evolution (LTE) (including LTE advanced (LTE-A)).

Both homogeneous and heterogeneous networks are considered, whose size and scale could be defined by topologic, geographic or demographic boundaries. An example of a network defined by topologic boundaries consists of a control node (whenever applicable), its supported access nodes and related network elements. Networks could also be defined by geographic boundaries, such as city-wide, national or continental, or they could be defined by demographic boundaries, such as urban or rural networks.

This Recommendation also applies to so-called "partial" networks, where energy efficiency is measured in some recommended way. The specification extends the measurements made in partial networks to the wider, so-called "total" network energy efficiency estimation, such as the network in a geographical area, the network in an entire country or the network of a mobile network operator (MNO).

Terminal (end-user) equipment is outside the scope of this Recommendation and is not considered in the energy efficiency measurement.

## 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.


[ITU-T L.1330] Recommendation ITU-T L.1330 (2015), *Energy efficiency measurement and metrics for telecommunication networks*.

[ITU-T Q.1742.1] Recommendation ITU-T Q.1742.1 (2002), *IMT-2000 references to ANSI-41 evolved core network with cdma2000 access network*.

[ETSI ES 202 336-12] ETSI ES 202 336-12 V1.1.1 (2015), *Environmental Engineering; Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunications networks); Part 12: ICT equipment power, energy and environmental parameters monitoring information model*.

[ETSI TS 123 203] ETSI TS 123 203 V12.7.0 (2015), *Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Policy and charging control architecture (3GPP TS 23.203 version 12.7.0 Release 12)*.

[ETSI TS 125 104] ETSI TS 125 104 V11.3.0 (2012), *Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104 version 11.3.0 Release 11)*.

[ETSI TS 132 405] ETSI TS 132 405 V11.1.1 (2013), *Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Performance Management (PM); Performance measurements; Universal Terrestrial Radio Access Network (UTRAN) (3GPP TS 32.405 version 11.1.1 Release 11)*.

[ETSI TS 132 412] ETSI TS 132 412 V11.1.0 (2013), *Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Performance Management (PM) Integration Reference Point (IRP): Information Service (IS) (3GPP TS 32.412 version 11.1.0 Release 11)*.

[ETSI TS 132 425] ETSI TS 132 425 V12.0.0 (2014), *LTE; Telecommunication management; Performance Management (PM); Performance measurements Evolved Universal Terrestrial Radio Access Network (E-UTRAN) (3GPP TS 32.425 version 12.0.0 Release 12)*.

[ETSI TS 136 104] ETSI TS 136 104 V11.2.0 (2012), *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 11.2.0 Release 11)*.

[ETSI TS 136 314] ETSI TS 136 314 V11.1.0 (2013), *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Layer 2 – Measurements (3GPP TS 36.314 version 11.1.0 Release 11)*.

[ETSI TS 152 402] ETSI TS 152 402 V11.0.0 (2012), *Digital cellular telecommunications system (Phase 2+); Telecommunication management; Performance Management (PM); Performance measurements – GSM (3GPP TS 52.402 version 11.0.0 Release 11)*.

[ISO/IEC 17025] ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*.

# 3 Definitions

## 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 backhaul equipment**: See [ITU-T L.1330]

**3.1.2 base station U**: See [ITU-T L.1330]

**3.1.3 distributed RBS**: See [ITU-T L.1330]

**3.1.4 energy efficiency (EE)**: See [ITU-T L.1330]

**3.1.5 energy saving feature**: See [ITU-T L.1330]

**3.1.6 integrated BS**: See [ITU-T L.1330]

**3.1.7 mobile network (MN)**: See [ITU-T L.1330]

**3.1.8 mobile network coverage energy efficiency**: See [ITU-T L.1330]

**3.1.9 mobile network data energy efficiency**: See [ITU-T L.1330]

**3.1.10 mobile network energy consumption**: See [ITU-T L.1330]

**3.1.11 mobile network energy efficiency**: See [ITU-T L.1330]

**3.1.12 mobile network operator (MNO)**: See [ITU-T L.1330]

**3.1.13 mobile network operator penetration ratio**: See [ITU-T L.1330]

**3.1.14 mobile network performance delivered**: See [ITU-T L.1330]

**3.1.15 power consumption**: See [ITU-T L.1330]

**3.1.16 radio access network**: See [ITU-T Q.1742.1]

**3.1.17 telecommunication network**: See [ITU-T L.1330]

**3.1.18 virtualized network function (VNF)** [b-ETSI GS NFV 003]: Implementation of an NF that can be deployed on a Network Function Virtualisation Infrastructure (NFVI).

### 3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

**3.2.1 site energy efficiency (SEE)**: A metric used to determine the energy efficiency of a telecom site. SEE is defined by the ratio of "IT equipment energy" and "Total site energy", which generally includes rectifiers, cooling, storage, security and IT equipment.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3GPP 3G (mobile) Partnership Project

BH Backhaul

BS Base Station

CC Central Cloud

CoA Coverage Area

CoA_geo total geographical area under investigation and within the operators' license agreement

CoA_des designated coverage area as designed by network planning

CoA_qdes quality factor describing how well users are covered within the coverage area

CR Coverage Ratio

CRAN Cloud Radio Access Network

CS Circuit Switched

DCA Designed Coverage Area

DL Downlink

DP Dominant Penetration

DU Dense Urban

DV Data Volume

$DV_{MN}$ Data Volume of the Mobile Network

EC Energy Consumption

$EC_{MN}$ Energy Consumption of the Mobile Network

EDC Edge Cloud

EE Energy Efficiency

$EE_{MN}$ Energy Efficiency of the Mobile Network

E-UTRA Evolved UMTS Terrestrial Radio Access Network

FAO Food and Agriculture Organization

GERAN GSM/EDGE Radio Access Network

GHG Greenhouse Gas

GSM Global System for Mobile communication

GSMA GSM Association

ICT Information Communications Technology

KPI Key Performance Indicator

LTE Long Term Evolution

MDT Minimization of Drive Tests

MJ MegaJoule

MN Mobile Network

MNO Mobile Network Operator

MP Minor Penetration

NA Not Applicable

NDP Non-Dominant Penetration

OAM Operations and Maintenance

PDF Probability Distribution Function

PS Packet Switched

PSL Packet Switched Large packages dominating

PSS Packet Switched Small packages dominating

PUE Power Usage Effectiveness

QCI QoS Class Identifier

QoS Quality of Service

RAB Radio Access Bearer

RAN Radio Access Network

RAP Remote Access Point

RAT Radio Access Technology

RC Radio Controller

RF Radio Frequency

RNC Radio Network Controller

RRC Radio Resource Control

RRH Remote Radio Head

| | |
|---|---|
| RU | Rural |
| SCH | Signalling Channel |
| SEE | Site Energy Efficiency |
| SI | Site Infrastructure |
| SINR | Signal to Interference plus Noise Ratio |
| SU | Suburban |
| TCH | Traffic Channel |
| TCO | Total Cost of Ownership |
| TMA | Tower Mounted Amplifier |
| U | Urban |
| UE | User Equipment |
| UE-BS | User Equipment to Base Station |
| UL | Uplink |
| UMTS | Universal Mobile Telecommunications Service |
| UN | United Nations |
| UTRAN | UMTS Terrestrial Radio Access Network |
| VNF | Virtualized Network Function |
| VoLTE | Voice over LTE |
| X2 | Interface allowing to interconnect eNBs with each other |

# 5 Conventions

None.

# 6 Network under test definition

## 6.1 Introduction

The mobile radio access network under investigation includes all the equipment that is necessary to run a radio access (RA) network or sub-network (see Figure 1 as a reference to the elements considered in this Recommendation).

- base stations (BSs) (see [ETSI TS 125 104] and [ETSI TS 136 104]):
  - wide area BS;
  - medium range BS;
  - local area BS;
  - home BS;

  NOTE – Home BS (and Wi-Fi access points) are not considered in this Recommendation, and are for further study.
- site equipment (e.g., air conditioners, rectifiers/ batteries, fixed network equipment);
- backhaul (BH) equipment required to interconnect the BS used in the assessment with the core network;
- radio controller (RC).

Power consumption and energy efficiency measurements of individual mobile network elements are described in several standards (e.g., [b-ETSI ES 202 706] for radio base stations). This Recommendation describes the energy consumption (EC) and mobile network (MN) energy efficiency measurements in operational networks.

As a comprehensive and detailed energy consumption measurement of the complete network of a country or mobile network operator (MNO) may not be viable, the total network is split into a small number of networks with limited size (i.e., "sub-networks").

These sub-networks are defined to represent specific characteristics, for example:

– capacity-limited networks representing urban (U) and dense urban (DU) networks;
– suburban (SU) networks with high requirements for coverage and capacity;
– rural (RU) networks, which are usually coverage limited.

The size and scale of the sub-networks are defined by topologic, geographic or demographic boundaries. For networks defined by topologic boundaries, an example could include: a radio controller, its supported access nodes and related network elements. Networks could also be defined by geographic boundaries, such as city-wide, national or continental networks. Networks could also be defined by demographic boundaries, such as urban or rural networks.

The sub-networks analysed might consist of macro-only base stations (BSs) or heterogeneous networks or what is actually implemented in real-world networks.

The tests defined in this Recommendation for sub-networks provide the basis to estimate energy efficiency for large networks of one MNO or within an entire country, applying the extrapolation methods described in clause 9.

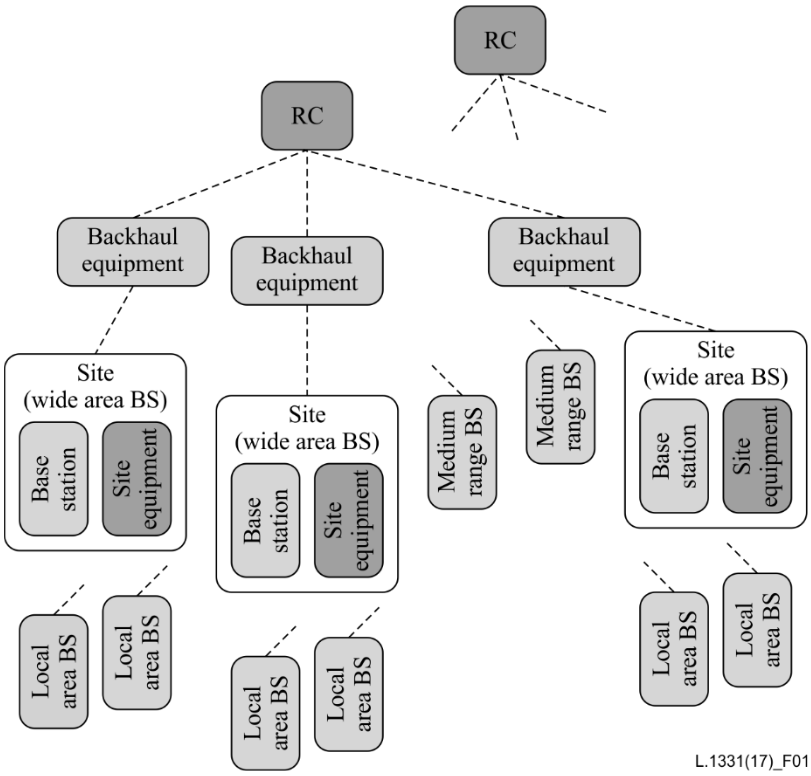


**Figure 1 – Network under test definition**

The functions outlined in Figure 1 could also be implemented in a cloud radio access network (CRAN). The first details of assessing energy efficiency in CRAN networks are outlined in Appendix II, but further investigated is needed.

## 6.2 Test parameter categorization

Metrics used for the energy efficiency assessment of mobile networks require the definition and collection of a range of parameters and variables. These are separated into two categories:

1) parameters and variables required to calculate the network energy efficiency;

2) parameters needed to allow network energy efficiency evaluation.

The first category describes a set of network variables as described in clause 7 (energy consumption, delivered bits, coverage) to be used to calculate the energy efficiency.

The second category includes parameters which are not directly required in the energy efficiency calculation. These parameters describe the network characteristics, such as geographical conditions, population density, coverage area, targeted data rates and climate zones, and are used to interpolate from the measured sub-network to a larger network as described in clause 9. These parameters can be used to interpret variations in energy efficiency results of different networks. Test parameters are listed in Table 1.

**Table 1 – Test parameter categorization**

| Category | Parameter | Remarks |
|---|---|---|
| 1 | $EC_{MN}$ | Measured network energy consumption |
| 1 | Capacity | As defined in clause 7.1 |
| 1 | Coverage area | As defined in clause 8.3.3 |
| 2 | Coverage ratio | As defined in clause 8.3.3 |
| 2 | Demography | Population density as defined in clause 6.3.2 |
| 2 | Topography | As defined in clause 6.3.3 |
| 2 | Climate zones | As defined in clause 6.3.4 |
| 2 | Informative classes | As defined in clause 6.3.5 |
| 2 | Circuit switched/packet switched data ratio | Describes the fraction of circuit switched traffic vs. packet switched traffic in the network |

## 6.3 Network classification

### 6.3.1 Introduction to network classification

To allow an extrapolation from the measured sub-networks (i.e., "partial" networks) to a complete network (i.e., "total" or "overall" networks), the test areas shall be classified into different categories as described in this clause.

The environmental classes used for network classification are: demography, topography and climate zones and are described in the following clauses.

### 6.3.2 Demography

For the test purposes defined in this Recommendation the mobile network is split into domains depending on the population density. The following population density values per domain categories are recommended, as reported in Table 2.

**Table 2 – Sub-network demography classes**

| Demography class | Typical population density (inhabitants/$km^2$) | Population range (inhabitants/$km^2$) |
|---|---|---|
| Dense urban (DU) | 20000 | > 10000 |
| Urban (U) | 2000 | 1000-10000 |
| Suburban (SU) | 300 | 200-1000 |
| Rural (RU) | 30 | 20-200 |
| Unpopulated | 0 | < 20 |

Some references to databases where the demography distribution classes are reported can be found at [b-European Eurostat], [b-UN Reference] and [b-USA Reference].

### 6.3.3 Topography

The following topography classes shall be used, as reported in Table 3.

**Table 3 – Sub-network topography classes**

| Topography classification | | Examples |
|---|---|---|
| ETSI class | Median slope | |
| 1<br>Flat<br>(FAO 1-3) | 0-5% | Denmark, Netherlands |
| 2<br>Rolling<br>(FAO 4-6) | > 5-30% | France, Italy |
| 3<br>Mountainous<br>(FAO 7-8) | > 30% | Norway, Switzerland |

Information on the median slope gradient distribution in the world can be found in the Food and Agriculture Organization (FAO) of the United Nations (UN) world median slope distribution information database [b-FAO].

### 6.3.4 Climate zones

The following climate zones are identified as reported in Table 4.

**Table 4 – Sub-network climate classes**

| Climate class | Subclass | Explanation |
|---|---|---|
| *A: Tropical* | *Temperature of the coldest month: > 18 °C* | |
| | Af | No dry season, at least 60 mm of rainfall in the driest month |
| | Am | Monsoon type, short dry season but sufficient moisture to keep ground wet throughout the year |
| | Aw | Distinct dry season, one month with precipitation < 60 mm |
| *B: Dry* | *Arid regions where annual evaporation exceeds annual precipitation, marked dry season* | |

**Table 4 – Sub-network climate classes**

| Climate class | Subclass | Explanation |
|---|---|---|
| | Bs | Steppe climate |
| | Bs | Desert |
| *C: Temperate* | *Average temperature of the coldest month < 18 °C and > −3 °C, and average temperature of warmest month > 10 °C* | |
| | Cw | Winter dry season, at least 10 times as much precipitation in the wettest month of summer than in driest month of winter |
| | Cs | Summer dry season, at least 3 times as much rain in the wettest month of winter than in the driest month of summer; the latter having less than 30 mm precipitation |
| | Cf | At least 30 mm precipitation in the driest month; the difference between the wettest month and the driest month less than for Cw and Cs |
| *D: Cold* | *Average temperature of the warmest month > 10 °C and that of coldest month < −3 °C* | |
| | Df | At least 30 mm of rain in the driest month; the difference between wettest month and the driest month less than for Cw and Cs |
| | Dw | At least 10 times as much precipitation in the wettest month of summer than in the driest month of winter |
| *E: Polar* | *Average temperature of the warmest month < 10 °C* | |
| | Et | Tundra, average temperature of warmest month > 0 °C |
| | Ef | No month with temperature > 10 °C |

The above reported climate classification is based on the FAO Koeppen classification [b-FAOclima].

The indication based on the five main classes A to E are recommended; the subclasses are optionally indicated.

### 6.3.5 Additional classification classes

To properly select the sub-networks operators' penetration, ratio and data traffic types could be reported for information. Table 5 reports the classification based on penetration classes and Table 6 reports the classification based on data volume (DV) classes.

**Table 5 – Sub-network penetration classes**

| Symbol | Operator penetration class | Range |
|---|---|---|
| DP | Dominant penetration | > 30% penetration |
| NDP | Non-dominant penetration | < 30% penetration |
| MP | Minor penetration | < 10% penetration |

**Table 6 – Sub-network data volume classes**

| Symbol | Traffic class | Specific thresholds |
|---|---|---|
| Circuit switched (CS) | CS dominating | > 50% of data volume is CS |
| Packed switched small (PSS) | PS – small packages dominating | > 50% of data volume is PS,<br>>80% of packages are small |

**Table 6 – Sub-network data volume classes**

| Symbol | Traffic class | Specific thresholds |
|---|---|---|
| Packet switched large (PSL) | PS – large packages dominating | > 50% of data volume is PS,<br>< 80% of packages are small |

# 7 Metrics for energy efficiency assessment

## 7.1 Introduction

The following metrics may be used to assess mobile network energy efficiency.

## 7.2 Energy consumption metrics

The energy consumption of the mobile network ($EC_{MN}$) is the sum of the energy consumption of equipment included in the MN under investigation (see clause 6). The network energy consumption is measured according to the assessment process defined in clause 8 such that individual metrics are provided per radio access technology (RAT) and per MNO.

$$EC_{MN} = \sum_i \left( \sum_k EC_{BS_{i,k}} + EC_{SI_i} \right) + \sum_j EC_{BH_j} + \sum_l EC_{RC_l} \qquad (1)$$

where:

- $EC$ is energy consumption
- $BS$ refers to the base stations in the MN under measurement
- $BH$ is the backhauling providing connection to the BSs in the MN under measurement
- $SI$ is the site infrastructure (e.g., rectifier, battery losses, climate equipment, tower mounted amplifier (TMA), tower illumination)
- $RC$ is the control node(s), including all infrastructure of the RC site
- $i$ is an index spanning over the number of sites
- $j$ an index spanning over the number of BH equipment connected to the $i$ sites
- $k$ is the index spanning over the number of BSs in the $i$-th site
- $l$ is the index spanning over the control nodes of the MN.

$EC_{MN}$ shall be measured in Wh over the period of measurement T (see clause 8).

NOTE 1 – If the control node(s) supports a larger MN than that which is assessed, only a proportional share of RC EC is considered, proportional to the radio network controller (RNC) share of traffic that belongs to the MN being assessed.

To allow for a more precise assessment of the energy consumption impact of local factors (e.g., location specific site equipment), it is requested to measure and report into the parameter $EC_{SI_i}$ the site equipment consumption into two classes:

1) information communications technology (ICT) equipment (equipment directly needed to perform the telecom service);
2) support equipment (all equipment installed at the site which are needed to operate the particular site, but which are not directly needed for the telecom service, such as air-conditioning, back-up power, lights).

Moreover, it is also requested to classify the site equipment according to operational temperature range.

Based on such a classification the following additional network key performance indicator (KPI) describing the energy consumption of the telecom equipment with reference to the total energy consumption is introduced:

$$SEE = EC_{BSs} / (EC_{BSs} + EC_{SI}) \qquad (1a)$$

The above metric gives an indication of site energy efficiency (SEE) in terms of the fraction of energy used for actual telecom equipment (see Figure 2).

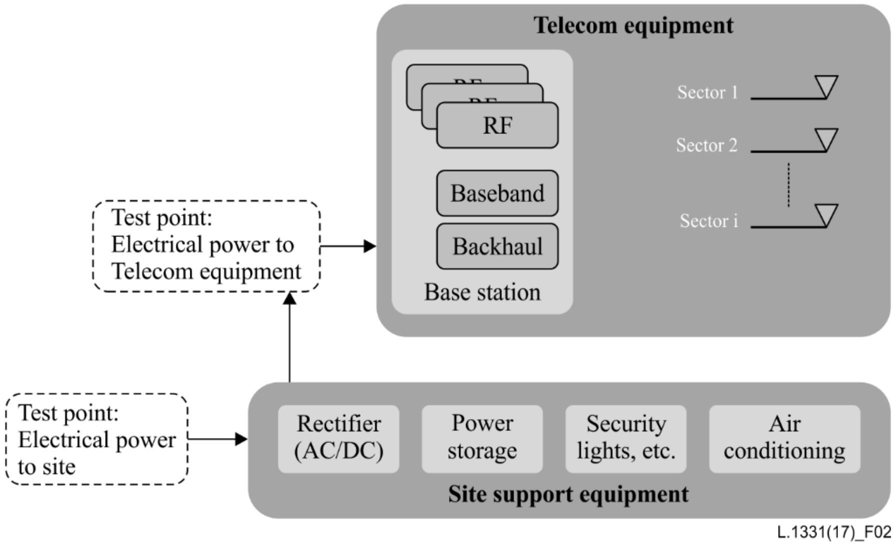


**Figure 2 – Layout of a typical site to determine the SEE metric**

NOTE 2 – Power generation is not part of MN energy efficiency, but it is reported for informational use for total cost of ownership (TCO) and greenhouse gas (GHG) analysis.

In currently deployed sites, there is a wide mixture of equipment installed within one room with different cooling requirements. The maximum room temperature is determined by the equipment with the lowest acceptable operating temperature. However, base station equipment is often designed to be operated at much higher temperatures.

The installed site equipment is classified into different environmental groups based on their operational temperature range (see Table 7). Such a classification allows the assessment of the energy saving potential if the site is split into areas for equipment which require cooling and others which can operate without.

**Table 7 – Environmental class categories for site equipment**

| Environmental class | Temperature range | IP (ingress protection) code |
|---|---|---|
| A | 0 … 28 °C | IP23 |
| B | −20 … 40 °C | IP45 |
| C | −40 … 55 °C | IP45 |

The energy sources available in the sites (e.g., power grid, generator set) shall be reported in the tables of clause 10 based on the typical layout reported in Figure 3 (where the notion of "extended telecom site" has been included to also include the on-site electricity generation and the "*" makes reference to the Telecom site as in Figure 2).

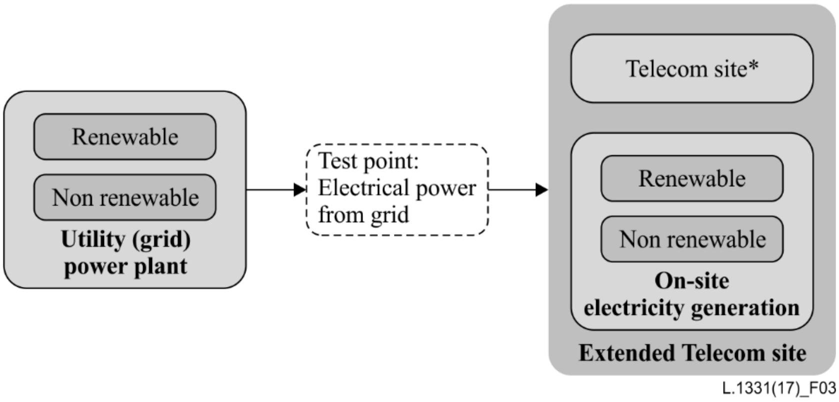


**Figure 3 – Schematic representation of the energy sources for a site**

The estimation of the environmental impact from the energy consumption requires additional parameters to be taken into consideration (e.g., GHG emissions or impact on the power grid dimensioning). Power consumption and power supply measurements/reports include:

– total electrical energy consumption of the site;
– total electrical energy consumption of the ICT equipment;
– total electrical energy supplied from the grid;
– peak power delivered from the grid;
– total energy supplied in a form other than electricity;
– total amount of energy generated at the site, separated between production type (e.g., generator set, solar, wind, fuel cell);
– total site energy storage capacity;
– peak shaving features available at the site.

### 7.3 Performance metrics

The MN performance metrics are derived from parameters of the MN under investigation (see clause 6) relevant to energy efficiency, in particular the total data volume of the mobile network ($DV_{MN}$) delivered by all its equipment and its global coverage area ($CoA_{MN}$).

For packet switched services, $DV_{MN}$ is defined as the data volume delivered by the equipment of the mobile network under investigation during the time frame T of the energy consumption assessment. The assessment process defined in clause 8 shall be used.

$$DV_{MN-PS} = \sum_{i,k} DV_{BS_{i,k}-PS} \quad (2)$$

where DV, measured in bits, is the performance delivered in terms of data volume in the network over the measurement period T (see clause 8). *i* and *k* are defined in equation (1).

For CS services like voice, $DV_{MN\text{-}CS}$ is defined as the data volume delivered by the equipment of the mobile network under investigation during the time frame T of the energy consumption assessment.

$$DV_{MN-CS} = \sum_{i,k} DV_{BS_{i,k}-CS} \quad (3)$$

where DV, measured in bits, is the performance delivered in terms of data volume in the network over the measurement period T (see clause 8). *i* and *k* are as defined in equation (1).

Note that "circuit switched", is meant here as all voice, interactive services and video services managed by the MNOs, including CS voice, voice over LTE (VoLTE) and real-time video services delivered through dedicated bearers. The assessment process defined in clause 8 shall be used.

The overall data volume is computed as follows:

$$DV_{MN} = DV_{MN-PS} + DV_{MN-CS} \quad (4)$$

$DV_{MN}$ can be derived from standard counters defined in [ETSI TS 132 425] and [ETSI TS 132 412] for LTE or equivalent used for 2G and 3G, multiplying by the measurement duration T. The counters (in [ETSI TS 132 425] and [ETSI TS 132 412]) also account for the quality of service (QoS) being reported in the QoS class identifier (QCI) basis (see [ETSI TS 123 203]).

NOTE 1 – $DV_{MN}$ includes data volumes for downlink (DL) and uplink (UL).

NOTE 2 – BH supervision and control data volumes are not considered (in order to include only the payload).

$DV_{MN}$ is computed in bits.

Coverage area ($CoA_{MN}$) is also considered as a mobile network performance metric in the MN designed primarily for coverage goals (and hence especially in RU environments). The assessment process defined in clause 8 shall be used. Coverage area is computed in $m^2$.

### 7.4 Mobile network energy efficiency metrics

Mobile network data energy efficiency ($EE_{MN,DV}$) is the ratio between the performance indicator ($DV_{MN}$) and the energy consumption ($EC_{MN}$) when assessed during the same time period.

$$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}} \quad (5)$$

where $EE_{MN,DV}$ is expressed in bit/J.

Mobile network coverage energy efficiency ($EE_{MN,CoA}$) is the ratio between the area covered by the MN under investigation (see clause 6) and the energy consumption when assessed during one year. $EE_{MN,CoA}$ is mainly used to complement $EE_{MN,DV}$ for MNs handling low data volumes, in particular in rural or deep rural areas. The area covered shall be assessed using rules (i.e., derived from geographic data or propagation models) defined in clause 8:

$$EE_{MN,CoA} = \frac{\mathrm{CoA\_des_{MN}}}{EC_{MN}} \quad (6)$$

where $EE_{MN,CoA}$ is expressed in $m^2$/J and $EC_{MN}$ is the yearly energy consumption and $\mathrm{CoA\_des_{MN}}$ is the "coverage area" as defined in clause 8.3.3.

## 8 Measurement of energy efficiency

### 8.1 Introduction

The measurement of the $EE_{MN}$ in the MN under investigation is based on the separate measurement of the performance (in terms of capacity and coverage) and energy, according to the metrics defined in clause 7.

### 8.2 Time duration of the measurement

The time duration of the measurement, denoted as T, shall be one of the alternatives:

– one week (7 days);

– one month (30 days);

– one year (365 days).

The minimum duration is therefore one week: monthly and yearly measurements are extensions of the basic weekly test. For the CoA metric the energy consumption shall always be extrapolated to a one-year time period. It is noted that T does not correspond to a granularity time or a repetition of the measurements time, that are optional values to be reported in clause 10 tables.

### 8.3 Measurement procedures

#### 8.3.1 Measurement of Energy Consumption

The energy consumption of the MN can be measured by means of metering information provided by utility suppliers or by mobile network integrated measurement systems. Moreover, sensors can be used to measure site and equipment energy consumption, following the requirements set by [ES 202 336-12].

The $EC_{MN}$ is based on site granularity and therefore includes all the equipment that is on the MNO sites (including the network controllers whenever applicable). The $EC_{MN}$ shall be differentiated per MNO providing service to the MN; in case of shared infrastructure the $EC_{MN}$ of the shared sites shall be computed per MNO sharing those sites in a proportional ratio. In case of separate metering per MNO the respective part of the $EC_{MN}$ shall be assigned to each MNO.

The $EC_{MN}$ shall be based on a per RAT estimation. If the sites contain BSs of different RATs the $EC_{MN}$ shall be measured for each RAT.

The list of equipment operating in the MN sites under investigation shall be reported in the assessment report, including cooling, power conversion, etc. For a site with multi RAT equipment the energy consumption of that equipment shall be split between each RAT proportionally to the configured radio frequency (RF) power transmitted by each RAT; further details on the multi RAT will be issued according to the development of multi RAT measurement in [b-ETSI ES 202 706].

The reporting frequency of the $EC_{MN}$ should be aligned with the energy provider settings and mobile network performance assessment settings and is reported in the assessment report.

NOTE – When a mobile network integrated measurement system according to [ETSI ES 202 336-12] is available, it should be used in addition to the utility provided $EC_{MN}$, allowing a more precise estimation of the consumption per RAT and per MNO.

#### 8.3.2 Measurement of capacity

The $DV_{MN}$ is measured using network counters for data volume related to the aggregated traffic in the set of BSs considered in the MN under test.

For packet switched (PS) traffic, the data volume is considered as the overall amount of data transferred to and from the users present in the MN under test. Data volume is measured in an aggregated way for each RAT present in the MN and is measured referring to counters derived from vendor operations and maintenance (OAM) systems.

For CS traffic (e.g., CS voice or VoLTE), the data volume is considered as the number of minutes of communications during the time T multiplied by the data rate of the corresponding service and the call success rate. The call success rate is equal to 1 minus the sum of blocking and dropping rates:

$$Call\ Success\ Rate = (1 - dropping\ rate) \times 100\ [\%] \qquad (7)$$

The dropping includes the intra-cell call failure (rate of dropping calls due to all causes not related to handover) and the handover failure:

$$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \qquad (8)$$

In order to include reliability in the measurement, the aggregated data volume shall be provided together with the 95th percentile of the cumulative distribution, for each RAT in the MN.

NOTE 1 – It is not possible for data services to determine a user related QoS, i.e., to identify for each data connection if a target throughput has been reached using counters. Such a computation would require the usage of probes that is out of scope of this Recommendation.

NOTE 2 – As soon as the minimization of drive tests (MDT)-related measurements in [ETSI TS 136 314] are available the data volume may be measured according to the specification given therein (especially referring to clause 4.1.8 in [ETSI TS 136 314]. In this case, the per-user information about QoS can be obtained for data services and only connections with good QoS should be considered.

### 8.3.3 Determination of coverage area

#### 8.3.3.1 Introduction

The coverage area is subject to network planning and intended services delivered within a certain geographical area. These parameters vary according to an MNO strategy and might therefore differ from MNO to MNO but also within the network of one MNO for different geographical areas. For the sake of energy efficiency assessment, drive tests and similar additional measurement campaigns are not required.

The coverage area is described by the following parameters:

– the total geographical area of a country (CoA_geo). This includes the total geographical area which falls into the network operators' responsibility (total network and/or sub-area under investigation). A network might cover the geographical area only to a certain fraction (often defined by the license agreements, e.g., area coverage of a complete country or of a region);

– the designated coverage area (CoA_des). This is the area in which network coverage is provided by the selected sub-network and it is derived by planning models from network design, planned service and geographical data;

– a coverage quality factor (CoA_qdes). This factor takes into account measured feedback from user equipment (as described in Tables 8-1 to 8-3). This coverage quality factor signifies that networks might experience false coverage issues (e.g., inside buildings), load congestions or high interference issues.

#### 8.3.3.2 Geographic coverage area

The geographic coverage area is the total two-dimensional area of a country, region or city where the MNO under test provides its service according to license agreements. This area might be not completely covered by the network. A license agreement might include a geographic coverage area (for example > 90% of the country area is covered) and an additional population coverage area (for example 98% of the population is covered).

#### 8.3.3.3 Designated coverage area

The designated coverage area is the area to be covered based on network planning and presents the actual geographical area where the operator officially promises coverage. This area is defined by the MNO's network service plan where the coverage, according to its license agreement or similar, is delivered. The area (sometimes referred to as "best server" area), is based on base station power, propagation conditions in the selected area, accepted outage criteria, and considered planning models (and therefore are hardly comparable).

The designated coverage area also includes in-building coverage. The in-building area (e.g., multi-story buildings) is only considered as the footprint of the building, not the buildings' actual floor space.

#### 8.3.3.4 Coverage quality

The actual coverage area where user equipment (UE) can be served might differ from the originally designated coverage area (i.e., false coverage zones within the considered area). The coverage quality is a measure of the actually covered fraction of the planned total coverage area. User equipment reports such as failed call attempts (see Tables 8-1 to 8-3) are used to determine how well the users within the coverage area are covered.

The coverage quality indicator is provided for network efficiency result evaluations. It is linked to network quality and has to be defined in relation to the quality of service (QoS) definitions.

A coverage map based on signal quality, the signal to interference plus noise ratio (SINR) as shown in Figure 4 could be used the determine the fraction of the total area where a signal quality above a certain minimum value is achieved. However, such maps require a large amount of field measurements.

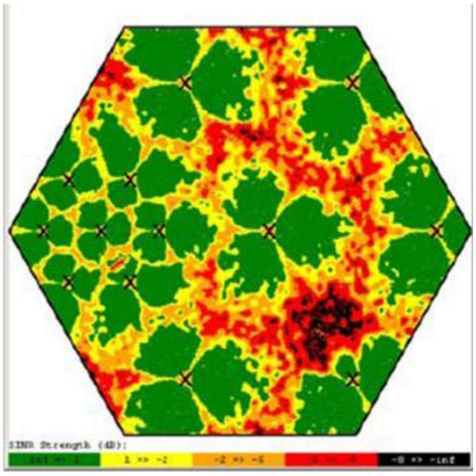


**Figure 4 – Typical SINR distribution of a mobile network**

For the sake of an energy efficiency assessment, it is not required to have knowledge of the detailed network conditions such as the actual coverage gap locations. From an energy efficiency assessment point of view it is important to know how many users/sessions or served users/sessions experienced problems because of the lack of sufficient quality in relation to the total number of users/sessions or served users/sessions within the considered area.

This allows a number of simplifications and an indirect determination of a quality factor.

The coverage quality factor (QF) for a base station is based on network failure reports of the UE.

The coverage quality factor shall be measured based on coverage failures reported by the appropriate network counters (see Tables 8-1 to 8-3):

CoA_Qdes = 1 – "percentage of users/sessions with coverage failure" (9)

The following indicators shall be used to calculate the coverage failure (for details, see Tables 8-1 to 8-3):

– radio resource control (RRC) setup failure ratio (call setup failure ratio);
– radio access bearer (RAB) setup failure ratio (UE-BS radio interface failure);
– RAB release failure ratio (UE-BS radio interface failure).

An additional factor which can indicate a coverage issue is the handover drop rate. However, a handover drop can have multiple reasons (e.g., cell overload, UE speed). Furthermore, the handover drop rate depends on the network structure (number of neighbouring cells). Its calculation requires several additional network parameters and significantly complicates the data collection and analysis. This factor is therefore omitted.

The coverage quality factor for a site is defined as follows:

CoA_Qdes = (1 – RRC setup failure ratio) (1 – RAB setup failure ratio) (1 – RAB release failure ratio) (10)

The parameters needed are specified by 3G (mobile) partnership project (3GPP) standards and the results can be obtained from the network management and supervision.

The failure ratios are the fraction of failures of the total number of attempts:

– RRC setup failure ratio = ($\Sigma_k$ Failed RRC connection establishment $s_k$)/($\Sigma_k$ attempted RRC connection establishment $s_k$);

– RAB setup failure ratio = ($\Sigma_k$ RAB setup failure$_k$)/($\Sigma_k$ RAB setup attempted$_k$);

– RAB release failure ratio = ($\Sigma_k$ RAB release failure$_k$)/($\Sigma_k$ RAB release attempted$_k$),

where *k* is the index spanning over the number of BSs in the considered site.

Tables 8-1, 8-2 and 8-3, which follow, report the measurement parameters required for coverage quality calculation. For LTE, see Table 8-1 (refer to ETSI TS 132 425 for definition/source), for UMTS, see Table 8-2 (refer to ETSI TS 132 405) and for GSM, see Table 8-3 (refer to ETSI TS 152 402).

**Table 8-1 – Measurement parameters required for coverage quality calculation for LTE**

| Parameter | Function | Counter name |
|---|---|---|
| RRC connection establishment failures | Radio resource control | RRC.ConnEstabFail.*sum* |
| RRC connection establishment attempts | Radio resource control | RRC.ConnEstabAtt.*sum* |
| E-RAB setup failures | Initial E-RAB setup | ERAB.EstabInitFailNbr.*sum* |
| | Additional E-RAB setup | ERAB.EstabAddFailNbr.*sum* |
| E-RAB setup attempts | Initial E-RAB setup | ERAB.EstabInitAttNbr.*sum* |
| | Additional E-RAB setup | ERAB.EstabAddAttNbr.*sum* |
| E-RAB release failures | E-RAB release | ERAB.RelFailNbr.*sum* |
| E-RAB release attempts | E-RAB release | ERAB.RelAttNbr.*sum* |

**Table 8-2 – Measurements parameters required for coverage quality calculations for UMTS**

| Parameter | Function | Counter name |
|---|---|---|
| RRC connection establishment failures | Radio resource control | RRC.FailConnEstab.*sum* |
| RRC connection establishment attempts | Radio resource control | RRC.AttConnEstab.*sum* |
| RAB setup failures | RAB setup for CS domain | RAB.FailEstabCSNoQueuing.*sum*,<br>RAB.FailEstabCSQueuing.*sum* |
| | RAB setup for PS domain | RAB.FailEstabPSNoQueuing.*sum*<br>RAB.FailEstabPSQueuing.*sum* |
| RAB setup attempts | RAB setup for CS domain | RAB.AttEstabCS.Conv.<U><D><br>RAB.AttEstabCS.Strm<br>RAB.AttEstabCS.Intact<br>RAB.AttEstabCS.Bgrd |
| | RAB setup for PS domain | RAB.AttEstabPS.Conv<br>RAB.AttEstabPS.Strm.<U><D><br>RAB.AttEstabPS.Intact<br>RAB.AttEstabPS.Bgrd |
| RAB release failures | RAB release for CS domain | RAB.FailRelCS.*sum* |
| | RAB release for PS domain | RAB.FailRelPS.*sum* |

**Table 8-2 – Measurements parameters required for coverage quality calculations for UMTS**

| Parameter | Function | Counter name |
|---|---|---|
| RAB release attempts | RAB release for CS domain | RAB.AttRelCS.*sum* |
| | RAB release for PS domain | RAB.AttRelPS.*sum* |

**Table 8-3 – Measurement parameters required for coverage quality calculations for GSM**

| Parameter | Function | Counter name |
|---|---|---|
| Immediate assignment success | IMMEDIATE ASSIGNMENT | succImmediateAssingProcs |
| Immediate assignment attempts | IMMEDIATE ASSIGNMENT | attImmediateAssingProcs |

The following averaging procedure is then used to obtain an average coverage quality factor of the partial network under test:

$$\mathrm{CoA\_Qdes}_{\mathrm{MN}} = \sum_{\mathrm{i}} CoA\_Qdes_{S_i} \mathrm{DCA}_{\mathrm{S_i}} / \sum_{\mathrm{i}} \mathrm{DCA}_{\mathrm{S_i}} \quad (11)$$

where:

S refers to the sites in the MN under measurement

*i* is an index spanning over the number of sites.

To avoid over-counting, the sites 'designed coverage' areas should be defined as the area where the signals from the cells of the site are stronger than the signals from adjacent cells. It holds true that:

$$\mathrm{CoA\_des}_{\mathrm{MN}} = \sum_{\mathrm{i}} \mathrm{DCA}_{\mathrm{S_i}} \leq \mathrm{CoA\_geo} \quad (12)$$

where:

S refers to the sites in the MN under measurement

*i* is an index spanning over the number of sites.

# 9 Extrapolation for overall networks

## 9.1 Extrapolation approach

The energy efficiency (EE) measured according to clauses 7 and 8 can be used to extrapolate to larger networks, as shown in Figure 5. When such an extrapolation is performed, it follows the method presented in this clause.

The sub-network data is extrapolated to overall/total networks according to demography, topography and climate classifications, as described in clause 6.

The extrapolation is done according to statistical information that indicates how recurrent the sub-network is within the total network to be addressed.

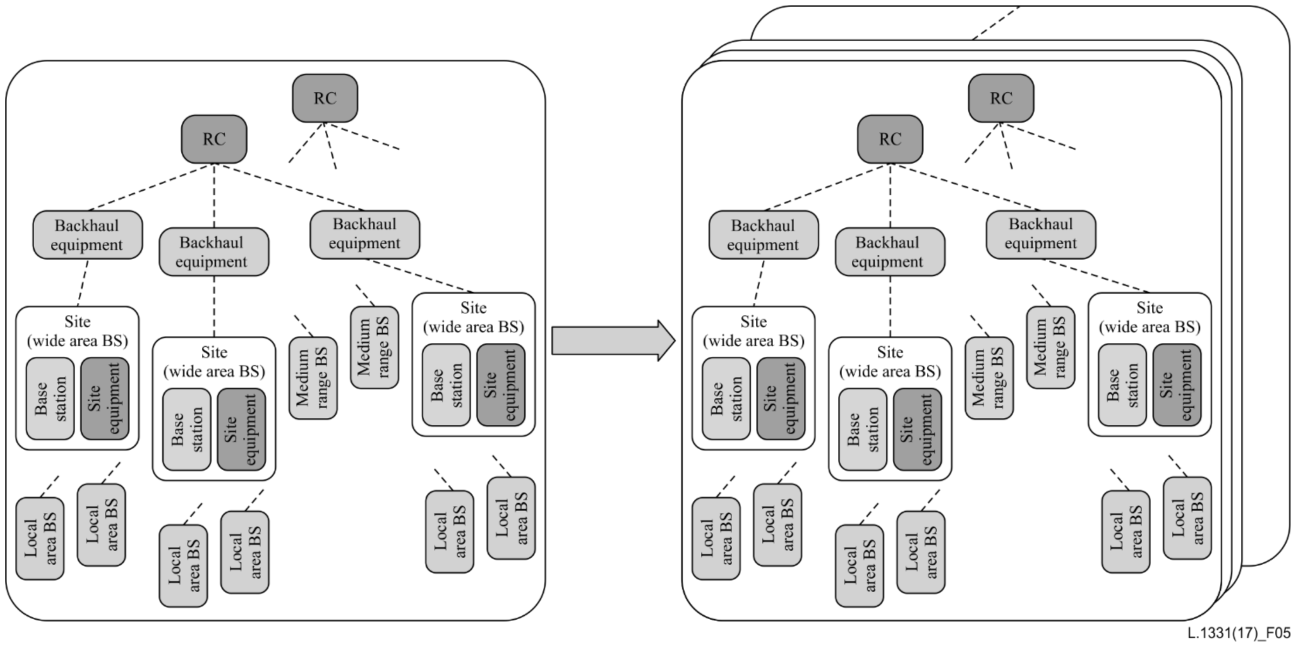


**Figure 5 – Extrapolation from one sub-network to a set of sub-networks ("total" network)**

## 9.2 Extrapolation method

### 9.2.1 Introduction of extrapolation method

In case the overall/total network to be addressed is not completely known in terms of demographical, topographical or climatological composition, or if the measurements of clause 7 and clause 8 are executed in some, but not all, the sub-networks, then the results shall be presented according to the tables in clause 10.

In such a case, an indication is needed for each sub-network, of its percentage recurrence with respect to the total network, in terms of demographical, topographical and climatological composition. Otherwise, if the exact composition of the total network is completely known, then the extrapolation shall be made to achieve the information valid for the total network.

– the extrapolation procedure should be based on the demographic information classes as reported in Table 2. It is optional to also make an extrapolation based on topography classes (Table 3) or on climate classes (Table 4) or on a combination of demography, topography and climate zones;

– the extrapolation should be based on a demographic number of classes sufficient to represent at least the 75% of the total network area's demographic distribution.

The following clauses show how to obtain data on the statistical distribution of demography, topography and climate zone classes in the networks under test at a total level. This information is to be used as a reference for every network area where this Recommendation will be used.

### 9.2.2 Statistical information about demography

An example of demographical information for Europe can be found in [ETSI TS 132 425], showing how to classify the sub-network under test under a demography class as in Table 2.

Another example, referring to UN information, is in [ETSI TS 132 412]. A further example for the USA can be found in [ETSI TS 123 203].

### 9.2.3 Statistical information about topography

An example of topography information can be found at the FAO world median slope distribution information, to classify the sub-network under test under a demography class as in Table 3.

### 9.2.4 Statistical information about climate zones

An example of topography information can be found in FAO Koeppen classification [b-FAOclima], which is used to classify the sub-network under test under a demography class as in Table 4.

## 9.3 Extrapolation reporting tables

### 9.3.1 Introduction of extrapolation reporting tables

Table 9 indicates how to report the data for extrapolation towards the total EE based on demography only. This is the recommended approach when extrapolation data are computed. Not all the classes are measured, only those classes that allow the coverage of at least 75% of the whole demographical distribution of the total area under measurement.

For all the sub-networks, the results of EE are reported according to the tables in clause 10 and the relative class shall be indicated. For all the same class measurements, an average of EE measurements shall be reported in Table 9; this shall be done both for data volume EE and for coverage area EE, whichever metric is used.

Then, for each class an average EE shall be computed as follows:

$$EE_{class,av} = \frac{\sum_k EE_{MN,k}}{K} \tag{13}$$

where "class" stands for one of the demography classes (DU, U, SU, RU or unpopulated), *k* is an index that runs over the number K of sub-networks per class.

The total EE should be computed as a weighted sum of all the averages available, the weights being the percentage of each demography class versus the sum of the available class's percentages. These percentages shall be derived from the information according to the examples of clause 9.2.

Then the total EE shall be computed as follows:

$$EE_{total} = \frac{\sum_m PofP_m EE_{class,av,m}}{\sum_m PofP_m} \tag{14}$$

where $PofP_m$ is the percentage of presence of the m-th demography class in the network under test, *m* is an index spanning over the number of classes and $EE_{class,av,m}$ is the m-th average as computed in equation (14).

### 9.3.2 Reporting extrapolation based on demography

The reporting extrapolation method based on demography is summarized in Table 9.

**Table 9 – Reporting extrapolation based on demography**

| **Demography classification** | **Percentage of presence (PofP) in the total network area of the class** | **$EE_{MN}$ in the class** | |
|---|---|---|---|
| | | **$EE_{MN,DV}$** | **$EE_{MN,CoA}$** |
| Dense urban (DU) | $PofP_{DU}$ [%] | $EE_{DU,av}$ | $EE_{DU,av}$ |
| Urban (U) | $PofP_U$ [%] | $EE_{U,av}$ | $EE_{U,av}$ |
| Suburban (SU) | $PofP_{SU}$ [%] | $EE_{SU,av}$ | $EE_{SU,av}$ |
| Rural (RU) | $PofP_{RU}$ [%] | $EE_{RU,av}$ | $EE_{RU,av}$ |
| Unpopulated | $PofP_{Unp}$ [%] | $EE_{Unp,av}$ | $EE_{Unp,av}$ |
| **Total EE** | | $EE_{total,DV}$ | $EE_{total,CoA}$ |

A demography table is the recommended extrapolation representation. In cases where the topography and climate zone classifications are available for the sub-networks measured according to clause 10 also Table 10 and Table 11 are to be reported.

### 9.3.3 Reporting extrapolation based on topography

The reporting extrapolation method based on topography is summarized in Table 10.

**Table 10 – Reporting extrapolation based on topography**

| Topography classification | Percentage of presence (PofP) in the total network area of the class | $EE_{MN}$ in the class | |
|---|---|---|---|
| | | $EE_{MN,DV}$ | $EE_{MN,CoA}$ |
| 1 Flat<br>(FAO 1-3) | $PofP_{Flat}$ [%] | $EE_{Flat,av}$ | $EE_{Flat,av}$ |
| 2 Rolling<br>(FAO 4-6) | $PofP_{Roll}$ [%] | $EE_{Roll,av}$ | $EE_{Roll,av}$ |
| 3 Mountainous<br>(FAO 7-8) | $PofP_{Mount}$ [%] | $EE_{Mount,av}$ | $EE_{Mount,av}$ |
| **Total EE** | | $EE_{total,DV}$ | $EE_{total,CoA}$ |

### 9.3.4 Reporting extrapolation based on climate zones

The reporting extrapolation method based on climate zones is summarized in Table 11.

**Table 11 – Reporting extrapolation based on climate zones**

| Climate zone classification | Percentage of presence (PofP) in the total network area of the class | $EE_{MN}$ in the class | |
|---|---|---|---|
| | | $EE_{MN,DV}$ | $EE_{MN,CoA}$ |
| A Tropical | $PofP_{Trop}$ % | $EE_{Trop,av}$ | $EE_{Trop,av}$ |
| B Dry | $PofP_{Dry}$ % | $EE_{Dry,av}$ | $EE_{Dry,av}$ |
| C Temperate | $PofP_{Temp}$ % | $EE_{Temp,av}$ | $EE_{Temp,av}$ |
| D Cold | $PofP_{Cold}$ % | $EE_{Cold,av}$ | $EE_{Cold,av}$ |
| E Polar | $PofP_{Polar}$ % | $EE_{Polar,av}$ | $EE_{Polar,av}$ |
| **Total EE** | | $EE_{total,DV}$ | $EE_{total,CoA}$ |

## 10 Assessment report

### 10.1 Introduction of assessment report

The results of the assessments shall be reported accurately, clearly, unambiguously and objectively, and in accordance with any specific instructions in the required method(s).

The report shall include tables defined in clauses 10.2 to 10.4. Items in italics can be considered optional.

Further guidelines on the test report can be found in clause 5.10 of [ISO/IEC 17025].

### 10.2 Report of network area under test

Table 12 reports the details of the network area under test, representing a sub-network where the measurements are conducted. The network area is the area encompassing all of the sites under measurement; the $\mathrm{CoA\_des_{MN}}$ is instead computed starting from the area covered by each site (as per clause 8) and aggregating for all the sites in the network area under test.

For each site reported in Table 12 the details shall be included in Table 13. Table 14 reports the measurements results for each site.

**Table 12 – Report of network area under test**

| **Network area under test** | | |
|---|---|---|
| Demography class<br>[dense urban, urban, suburban, rural, sparse] [Table 2] | | |
| Topography class [Table 3] | | |
| Climate zone [Table 4] | | |
| Informative classification [Tables 5 and 6] | | |
| Network area definition<br>[by demography, by geography, by topology] | | |
| | *Number of inhabitants in the network area*<br>*[estimate]* | |
| | Network area dimensions<br>[estimate, km²] | |
| | Number of sites in the network area<br>[same radio controller?] | |
| Type of sites in the network area | | |
| | Number of wide area BS sites | |
| | Number of medium range BS sites | |
| | Number of other sites/equipment<br>(local area BS, relay nodes, etc.) | |
| Sites categorization | | |
| | Number of sites in an MNO<br>local exchange premise | |
| | Number of sites in buildings not owned by MNO | |
| | Number of sites in a shelter | |
| | *Number of any other sites* | |
| Multi-MNO sites | | |
| | Number of "single MNO" sites | |
| | Number of co-located multi-MNOs sites | |
| | Number of sites in "network sharing" mode | |

**Table 12 – Report of network area under test**

| Network area under test | | |
|---|---|---|
| Multi-technology sites | | |
| | Number of 2G-only sites | |
| | Number of 3G-only sites | |
| | Number of LTE-only sites | |
| | Number of 2G+3G sites | |
| | Other options [indicate] | |
| Backhauling information | | |
| | Predominant type of backhauling [wireless, fibre, copper…] | |
| | Number of backhauling links per type | |
| Energy efficiency in the network area | | |
| | $EE_{MN,DV}$ [b/J] | |
| | $EE_{MN,CoA}$ [m$^2$/J] | |
| Energy efficiency top-down approach results (see note) | | |
| NOTE – In case any alternative EE approach has been conducted on the network under test (i.e., measuring the aggregated energy consumption and the aggregated data volume or coverage area) the results of the evaluation shall be reported here for comparison purposes. | | |

## 10.3 Report of sites under test

**Table 13 – Report of sites under test**

| Site(s) under test in the network area<br>(one table per site type to be measured in the network area) | | |
|---|---|---|
| Measurement duration | | |
| | Time duration of the measurement [T] | |
| | *Measurement start date and time* | |
| | *Measurement finish date and time* | |
| | *Repetition time* | |
| | *Granularity of measurements* | |
| Type of site | | |
| | Site "layer"<br>[wide area, medium range, other]<br>In case of wide area, indicate number of sectors and carriers per sector | |
| | Site "technology"<br>[2G, 3G, 2G+3G, LTE only, 2G+3G+LTE, other] | |
| | Site "MNOs"<br>[single MNO, co-location, network sharing, other] | |

**Table 13 – Report of sites under test**

<table>
<tr><th colspan="3">Site(s) under test in the network area<br>(one table per site type to be measured in the network area)</th></tr>
<tr><td>Site and equipment age<br>• Initial commission date of the site<br>• Commission date of the current equipment in the site</td><td></td><td></td></tr>
<tr><td>Temperature<br>• Average temperature [over period T]<br>• Minimum temperature<br>• Maximum temperature</td><td>Internal °C</td><td>External °C</td></tr>
<tr><td>Environmental class Temp. range IC class (for each equipment in the site)<br>A 0 ... 28 °C IP23<br>B –20 ... 40 °C IP45<br>C –40 ... 55 °C IP45</td><td colspan="2"></td></tr>
<tr><td colspan="3">Site infrastructure</td></tr>
<tr><td rowspan="7"></td><td>Site location<br>[local exchange premise, building, shelter, other]</td><td></td></tr>
<tr><td>Site composition</td><td></td></tr>
<tr><td>• air conditioners</td><td></td></tr>
<tr><td>• rectifiers/batteries</td><td></td></tr>
<tr><td>• fixed network equipment consumption</td><td></td></tr>
<tr><td>• other</td><td></td></tr>
<tr><td>Estimated percentage of infrastructure consumption in the site ($EC_{si}$)</td><td></td></tr>
<tr><td>Energy consumption of ICT equipment in the site [Wh]</td><td colspan="2"></td></tr>
<tr><td>Energy consumption of all the support equipment in the site [Wh]</td><td colspan="2"></td></tr>
<tr><td>Energy efficiency in the site equipment (Energy_ICTequipment / Energy_Total_network)</td><td colspan="2"></td></tr>
<tr><td>– total electrical energy supplied from the grid<br>– peak power delivered from the grid<br>– total site energy storage capacity<br>– peak shaving features available at the site</td><td colspan="2"></td></tr>
<tr><td>Energy efficiency enhancement methods affecting the site equipment during the test</td><td colspan="2"></td></tr>
</table>

**Table 13 – Report of sites under test**

| Site(s) under test in the network area<br>(one table per site type to be measured in the network area) | | |
|---|---|---|
| *Estimated percentage of presence of this site type in the network area* | | |
| Electricity sources used in the site | | |
| | Electricity [%] | |
| | Generator set [%] | |
| | Solar [%] | |
| | Renewables [%] | |
| | Others (indicate) | |

## 10.4 Report of site measurement

**Table 14 – Report of site measurement**

| Site measurement | | |
|---|---|---|
| Measurement duration | | |
| | Time duration of the measurement [T] | |
| | *Measurement start date and time* | |
| | *Measurement finish date and time* | |
| | *Repetition time* | |
| | *Granularity of measurements* | |
| Temperature class and average temperature during the test | | |
| Energy consumption in the site | | |
| | Method of measurement<br>[energy bills/counters, sensors, equipment information, other] | |
| | Measured energy consumption $EC_{MN}$ [Wh or multiples] | |
| | • *weekly energy consumption [per week data/graph]* | |
| | • *monthly energy consumption [if T allows]* | |
| | • *yearly energy consumption [if T allows]* | |
| Traffic offered in the site | | |
| | Method of measurement<br>[operational counters, backhauling data, MDT, other] | |
| | Measured traffic volume DV [bit or multiples] | |
| | • *weekly traffic [per week data/graph]* | |
| | • *monthly traffic [if T allows]* | |
| | • *yearly traffic [if T allows]* | |
| Coverage of the site [data to be reported per each RAT present in the site] | | |
| | CoA_geo: [$km^2$] | |
| | CoA_des: [$km^2$] | |

**Table 14 – Report of site measurement**

| **Site measurement** | | |
|---|---|---|
| | CoA_Qdes: | |
| | • failed RRC connection establishments<br>• attempted RRC connection establishments<br>• RAB setup failure<br>• RAB setup attempted<br>• RAB release failure<br>• RAB release attempted | |
| Site energy efficiency | | |
| | Measured energy efficiency $EE_{MN}$ [bit/J] and [$m^2$/J] | |
| | • *Weekly energy efficiency [per week data/graph]* | |
| | • *Monthly energy efficiency [if T allows]* | |
| | • *Yearly energy efficiency [if T allows]* | |

## 11 Implementation guidelines

This Recommendation is based on the mobile network area definition under test as described in clause 6, where measurements have to be done according to the metrics as defined in clause 7 and following the procedures as defined in clause 8. In this way, the network under test is evaluated in terms of energy efficiency and the results obtained therein are to be filled in the tables reported as an essential part of the specification in clause 10.

Extrapolation of sub-network results can be used for the assessment of larger networks, in particular when measurements over the total network are not possible due to its dimensions. In this case, the extrapolation approach defined in clause 9 is recommended.

Careful selection of the sub-networks for measurement is needed to ensure that the results are technically sound and, even if this is not the primary goal, comparable. Of course, results measured in very different environments (different in terms of demography or climatology or topography, but also different due to the goal and function of the network) are hardly comparable and, as said, the purpose of the specification is not to make comparable what is not, but the important issue is to introduce a method of testing that can represent a common reference whenever a test of mobile network energy efficiency is performed over an RA network.

In the case where a network is tested against itself in different time periods, a comparison is sensible only with the attention due to all the parameters listed in the tables of clause 10, especially when referring to temperature and environmental conditions. This highlights the possible reasons for changes in energy efficiency. When considering these parameters, the accuracy of the measurements has to be reported, to ensure the utmost consistency of measurements made in different time periods.

If, in given regions, there are regulation constraints that impose some rules in the deployment of networks, this has to be kept in mind when making any comparison. In such cases only the comparison of networks with the same constraints are sensible.

Regarding the time duration T of the measurements campaigns, the period of the measurements has to be chosen in the most sensible way in terms of particular foreseeable traffic conditions, weather impacts, etc.

An essential part of this common base method is represented by the tables in clause 10. Even in very different scenarios these tables should be filled in completely in order to have the measurement accepted as based on this Recommendation. The test will be considered compliant if, when the measurements are done in very different scenarios, the details of the scenarios are reported in the tables, considering not only the final energy efficiency results but also how they have been obtained

# Appendix I

## Implementation examples

(This appendix does not form an integral part of this Recommendation.)

### I.1 Implementation examples

Considering the implementation guidelines reported in clause 11, a set of examples on how to implement this Recommendation is given here.

As one example, a possible application of this Recommendation is to provide national authorities a commonly accepted procedure to estimate at a national, regional or city-level the efficiency of a radio access technology or a set of RATs deployed by an MNO or a set of MNOs. This assessment can be stand alone, to understand what efficiency is reasonably achievable, or it can be estimated towards a given threshold, to ensure that better efficiency is achieved (e.g., after the introduction of new energy savings procedures, or new hardware solutions).

As another example, this Recommendation could be used to test the efficiency of a network, year-over-year, or in any case against a given time roadmap. The test can be performed over the same sub- or total network, depending on the requirements, and over the network of the same MNO, in a different period of time, i.e., year-over-year or in any case so as to emphasize a time evolution of the EE performances. Even in this case, the full completion of the information in tables in clause 10 is mandatory to check under which conditions the tests have been performed.

As a final example, this Recommendation could be used without any extrapolation phase (as described in clause 9) when the purpose is to evaluate network functionalities that impact energy efficiency in a small network under test. In such a case this Recommendation indicates how to proceed to compare such small networks when the mentioned functionalities are activated with respect to the baseline case, when the functionalities are not active.

### I.2 Examples of reporting data

In this clause, an example of the data to be filled in into the tables of clause 10 and clause 9 is given. This example is for explanation purposes only, and the data reported are not to be considered real or binding in any way.

Table I.1 is Table 12 filled in with example data.

**Table I.1**

| **Network area under test (partial network #1)** | |
|---|---|
| Demography class<br>[dense urban, urban, suburban, rural, sparse] [Table 2] | Dense urban |
| Topography class [Table 3] | Flat |
| Climate zone [4] | Temperate |
| Informative classification [Tables 5 and 6] | DP, PSL |
| Network area definition<br>[by demography, by geography, by topology] | Demography |

**Table I.1**

| Network area under test (partial network #1) | | |
|---|---|---|
| | *Number of inhabitants in the network area [estimate]* | 150000 |
| | Network area dimensions [estimate, km²] | 15 $km^2$ |
| | Number of sites in the network area [same radio controller?] | 30, of the same RC |
| Type of sites in the network area | | |
| | Number of wide area BS sites | 25 |
| | Number of medium range BS sites | 3 |
| | Number of other sites/equipment (local area BS, relay nodes, etc.) | 2 |
| Sites categorization | | |
| | Number of sites in an MNO local exchange premise | 5 |
| | Number of sites in buildings not owned by MNO | 20 |
| | Number of sites in a shelter | |
| | *Number of any other sites* | 5 |
| Multi-MNO sites | | |
| | Number of "single MNO" sites | 20 |
| | Number of co-located multi-MNOs sites | 8 |
| | Number of sites in "network sharing" mode | 2 |
| Multi-technology sites | | |
| | Number of 2G-only sites | 0 |
| | Number of 3G-only sites | 10 |
| | Number of LTE-only sites | 5 |
| | Number of 2G+3G sites | 10 |
| | Other options [indicate] | 5 2G+3G+LTE |
| Backhauling information | | |
| | Predominant type of backhauling [wireless, fibre, copper…] | Fibre, copper |
| | Number of backhauling links per type | 20 fibre, 10 copper |
| Energy efficiency in the network area | | |
| | $EE_{MN,DV}$ [b/J] | 180 b/J |
| | $EE_{MN,CoA}$ [$m^2$/J] | 3 $m^2$/MJ |
| Energy efficiency top-down approach results | | |
| | 100 bit/J | |

Table I.2 reports an example of a site in the partial network #1 described in Table I.1.

**Table I.2**

| **Site(s) under test in the network area<br>(one table per site type to be measured in the network area)** | | |
|---|---|---|
| Measurement duration | | |
| | Time duration of the measurement [T] | 2 weeks |
| | *Measurement start date and time* | 2014/07/07 |
| | *Measurement finish date and time* | 2014/07/20 |
| | *Repetition time* | Daily |
| | *Granularity of measurements* | 1 min |
| Type of site | | |
| | Site "layer"<br>[wide area, medium range, other]<br>In case of wide area, indicate number of sectors and carriers per sector | Wide area,<br>3 sectors<br>2 carriers each sector |
| | Site "technology"<br>[2G, 3G, 2G+3G, LTE only, 2G+3G+LTE, other] | 3G |
| | Site "MNOs"<br>[single MNO, co-location, network sharing, other] | Single MNO |
| *Site and equipment age*<br>*Initial commission date of the site*<br>*Commission date of the current equipment in the site* | | 2005/11/05 initial<br>2013/07/22 current equipment |
| *Temperature*<br>*Average temperature [over period T]*<br>*Minimum temperature*<br>*Maximum temperature* | *Internal °C*<br>*24,2 °C*<br>*18,8 °C*<br>*30,6 °C* | *External °C*<br>*28,3 °C*<br>*19,6 °C*<br>*36,4 °C* |
| Site infrastructure | | |
| | Site location<br>[local exchange premise, building, shelter, other] | Outdoor cabinet |
| | Site composition | |
| | • air conditioners | Yes, 2 kW average power |
| | • rectifiers/ batteries | Yes, both; 250 W average power |
| | • fixed network equipment consumption | |
| | Other | |
| | *Estimated percentage of infrastructure consumption in the site ($EC_{si}$)* | 50% |

**Table I.2**

| Site(s) under test in the network area<br>(one table per site type to be measured in the network area) | | |
|---|---|---|
| Energy consumption of ICT equipment in the site [Wh] | 1,5k | |
| Energy consumption of all the support equipment in the site [Wh] | 2k | |
| Energy efficiency in the site equipment (Energy_ICTequipment / Energy_Total_network) | 1,5/3,5=0,43 | |
| – total electrical energy supplied from the grid<br>– peak power delivered from the grid<br>– total site energy storage capacity<br>– peak shaving features available at the site | TBD | |
| Energy efficiency enhancement methods affecting the site equipment during the test | Traffic related power off of the second carrier | |
| *Estimated percentage of presence of this site type in the network area* | 33% | |
| Electricity sources used in the site | | |
| | Mains/power grid [%] | 80% |
| | Generator set [%] | – |
| | Solar [%] | 20% |
| | Other renewables [%] | – |
| | Others (indicate) | – |

Table I.3 reports the measurement in the site described in Table I.2.

**Table I.3**

| Site measurement | | |
|---|---|---|
| Measurement duration | | |
| | Time duration of the measurement [T] | 2 weeks |
| | *Measurement start date and time* | 2014/07/07 |
| | *Measurement finish date and time* | 2014/07/20 |
| | *Repetition time* | Daily |
| | *Granularity of measurements* | 1 min |
| Temperature class and average temperature during the test | | |
| Class C, average internal temperature 24.2 °C | | |
| Energy consumption in the site | | |

**Table I.3**

| Site measurement | | |
|---|---|---|
| | Method of measurement<br>[energy bills/counters, sensors, equipment information, other] | Sensors |
| | Measured energy consumption $EC_{MN}$ [Wh or multiples] | |
| | • *Weekly energy consumption [per week data/graph]* | *Introduce a graph of the kWh in the site, or a table of values, per each week, according to the time granularity of the available data* |
| | • *Monthly energy consumption [if T allows]* | NA |
| | • *Yearly energy consumption [if T allows]* | NA |
| Traffic offered in the site | | |
| | Method of measurement<br>[operational counters, backhauling data, MDT, other] | Operational counters |
| | Measured traffic volume DV [bit or multiples] | |
| | • *Weekly traffic [per week data/graph]* | *Introduce a graph of the Gb in the site, or a table of values, per each week, according to the time granularity of the available data* |
| | • *Monthly traffic [if T allows]* | NA |
| | • *Yearly traffic [if T allows]* | NA |
| Coverage of the site [data to be reported per each RAT present in the site] | | |
| | CoA_geo: [$km^2$] | 0,5 |
| | CoA_des: [$km^2$] | 0,42 |
| | CoA_qdes: | 84% |
| | • failed RRC connection establishments<br>• attempted RRC connection establishments<br>• RAB setup failure<br>• RAB setup attempted<br>• RAB release failure<br>• RAB release attempted | 658<br>13118<br>322<br>4998<br>294<br>4998 |
| Mobile network energy efficiency | | |
| | Measured energy efficiency [bit/J] | |
| | • *Weekly energy efficiency [per week data/graph]* | *Introduce a graph of the bit/J in the site, or a table of values, per week, according to the time granularity of the available data* |
| | • *Monthly energy efficiency [if T allows]* | NA |
| | • *Yearly energy efficiency [if T allows]* | NA |

Table I.4 reports an example of computation results of a total mobile network energy efficiency assessment. The EE values are in the format of tables for partial network #1, and other values are considered in other partial networks in the same partial network area (not reported in this example) to come to the average values in the EE columns. The total EE is evaluated in the measurement period T timeframe (2 weeks) for the DV case, while EC is extrapolated to 1 year as required for CoA EE metric.

**Table I.4**

| **Demography classification** | **Percentage of presence (PofP) in the total network area of the class** | **$EE_{MN}$ in the class** | |
|---|---|---|---|
| | | **$EE_{MN,DV}$** | **$EE_{MN,CoA}$** |
| Dense urban (DU) | 42% | *200 b/J* | *2,7 $m^2$/MJ* |
| Urban (U) | 20% | *40 b/J* | *19 $m^2$/MJ* |
| Suburban (SU) | 15% | *8 b/J* | *38 $m^2$/MJ* |
| Rural (RU) | 13% | *2 b/J* | *115 $m^2$/MJ* |
| Unpopulated | 10% | *NA* | *NA* |
| **Overall/total EE** | | ***103,8 b/J*** | ***28,4 $m^2$/MJ*** |

In order to better clarify the example in table I.4 the following equations explain how to compute the total EE in the cases mentioned above.

$$EE_{total,DV} = \frac{PofP_{DU} * EE_{DU,av} + PofP_{U} * EE_{U,av} + PofP_{SU} * EE_{SU,av} + PofP_{Unp} * EE_{Unp,av}}{PofP_{DU} + PofP_{U} + PofP_{SU} + PofP_{Unp}}$$
$$= \frac{42 * 200 + 20 * 40 + 15 * 8 + 13 * 2}{42 + 20 + 15 + 13} = 103{,}8\ b/J$$

$$EE_{total,CoA} = \frac{PofP_{DU} * EE_{DU,av} + PofP_{U} * EE_{U,av} + PofP_{SU} * EE_{SU,av} + PofP_{Unp} * EE_{Unp,av}}{PofP_{DU} + PofP_{U} + PofP_{SU} + PofP_{Unp}}$$
$$= \frac{42 * 2{,}7 + 20 * 19 + 15 * 38 + 13 * 115}{42 + 20 + 15 + 13} = 28{,}4\ m^2/MJ$$

Note that in the CoA case the extrapolation has been made from T = 14 days to 1 year dividing by 26 the results during period T (365/14~26).

# Appendix II

# Cloud RAN energy efficiency

(This appendix does not form an integral part of this Recommendation.)

The objective of this appendix is to provide the minimum information on definitions and principles to be used for the assessment of energy efficiency of cloud RAN (CRAN) networks. Further details on the CRAN architecture and implementation of energy efficiency of cloud RAN (EECRAN) assessment are still under investigation (e.g., SooGreen EU research project) and can be provided in future revisions of this Recommendation as appropriate.

## II.1 Generic CRAN architecture layout and definitions

As far as energy efficiency assessment is concerned, the generic architecture of CRAN can be divided into three domains: central cloud, edge cloud and radio access. The generic layout design is defined in Figure II.1.

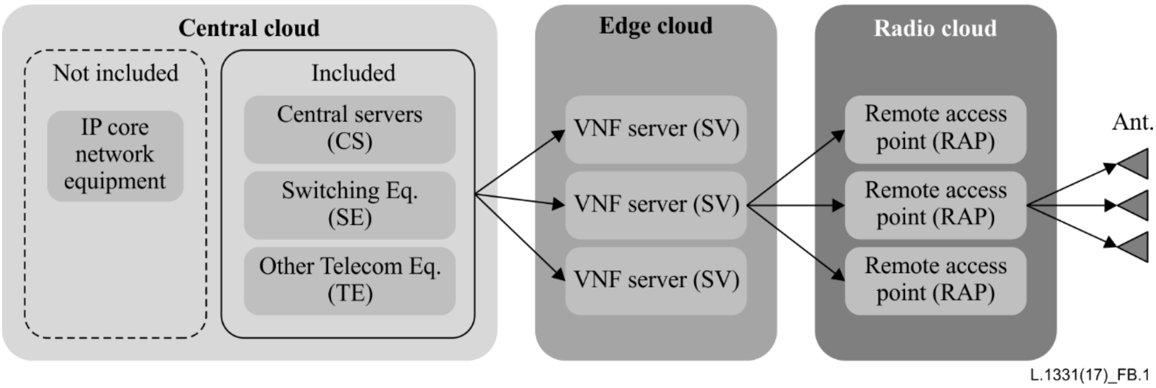


**Figure II.1 – Generic CRAN architecture layout**

The RA domain consists of remote access points (RAPs) dedicated to the CRAN under investigation. A typical RAP would include the radio, baseband and optical transport equipment. It would perform real-time eNB tasks (e.g., scheduler). It is installed near the transmitting antennas (e.g., within 1 m to 1 km). The density of RAPs deployed for the CRAN would vary with different implementations, but typically would be of a few RAP units per 10 km². A typical value of RAP energy efficiency is: $SEE_{RAP}$ = 90%.

The edge cloud (EDC) domain consists of small datacentres dedicated to telecom functions, including virtualized network function (VNF) servers (VNFSs) used by the CRAN under investigation. A typical EDC datacentre would perform non-real-time eNB tasks, such as OAM. The density of EDC datacentres deployed for the CRAN varies with different network configurations, but typically would be a few units per 100 km². A typical value of EDC site energy efficiency is: $SEE_{EDC}$ = 75%.

The central cloud (CC) domain consists of a multi-server datacentre including central servers, switching equipment and other telecom equipment if needed. IP core network equipment should not be taken into account in the assessment of CRAN energy consumption. CC datacentres are usually very far from most of the served EDCs. Their density would vary with different network configurations, but would be typically be of a few units per 100000 km². A typical value of CC site energy efficiency is: $SE_{ECC}$ = 65%.

## II.2 Energy consumption and efficiency assessment

The following equations should be used in the EE assessment:

- Data volume

$$DV_{CRAN} = \sum_{RAP}(DV_{RAP-DL} + DV_{RAP-UL}) \qquad \text{(II.1)}$$

where:

$DV_{RAP-DL}$ and $DV_{RAP-UL}$ are the data volume of the RAP for DL and UL, respectively.

- Energy consumption:

$$EC_{CRAN} = \sum_{CC\ sites}\left(\sum_{site}(EC_{CS} + EC_{SE} + EC_{TE})\right)\Big/SEE_{CC} \cdot + \sum_{EDC\ sites}\left(\sum_{Site}EC_{VNFS}\right)\Big/SEE_{EDC} + \sum_{RAP}EC_{RAP}/SEE_{RAP}$$

- Energy efficiency:

$$EE_{CRAN} = DV_{CRAN}/EC_{CRAN}$$

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