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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

Energy efficiency, smart energy and green data centres

Assessment of mobile network energy efficiency

Recommendation ITU-T L.1331

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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

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Introduction

Recommendation ITU-T L.1331 considers the definition of metrics and methods used to measure the energy 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 [b-ETSI TR 103 117]. Measurements in testing laboratories of the efficiency of the base stations is treated in [b-ETSI ES 202 706-1].

Recommendation ITU-T L.1331 also provides a method to extrapolate 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; implementation guidelines are given in clause 11. 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 in particular considering the networks' evolution in different periods of time. 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 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), long term evolution (LTE) and 5G New Radio (NR).

Aiming to also consider the slicing approach of the networks from 5G onwards, the metrics are extended to the latency of the network itself versus the energy consumed, in addition to the metrics based on traffic and on coverage, already existing for legacy networks that are still valid.

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, for which a measurement method is also recommended. 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*.

[ITU-R M.2410-0] Recommendation ITU-R M.2410-0 (2017), *Minimum requirements related to technical performance for IMT-2020 radio interface(s)*.

[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 128 554] ETSI TS 128 554 V15.2.0 (2019), *5G; Management and orchestration; 5G end to end Key Performance Indicators (KPI)*.

[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 **end-to-end latency** [b-ETSI TS 122 261]: The time that it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.1.19 **virtualized network function (VNF)** [b-ETSI GS NFV 003]: Implementation of an NF that can be deployed on a Network Function Virtualization 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 telecommunication 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:

O&M	Operation and Maintenance
BH	Backhaul
BS	Base Station
CC	Central Cloud
CoA	Coverage Area
CoA_geo	total geographical area under investigation and within the operators' licence 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
DC	Data Centre
DCA	Designed Coverage Area
DL	Downlink
DP	Dominant Penetration
DU	Dense Urban
DV	Data Volume
DV_{MN}	Data Volume of the Mobile Network
E2E	End-to-End
EC	Energy Consumption
EC_{MN}	Energy Consumption of the Mobile Network
EDC	Edge Cloud
EDGE	Enhanced Data GSM Environment
EE	Energy Efficiency
EE_{MN}	Energy Efficiency of the Mobile Network
E-UTRA	Evolved UMTS Terrestrial Radio Access Network
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
GSM	Global System for Mobile communication
HARQ	Hybrid Automatic Repeat Request
ICT	Information Communications Technology
KPI	Key Performance Indicator
LC	Local Cloud
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MN	Mobile Network
MNO	Mobile Network Operator
MP	Minor Penetration
NA	Not Applicable
NR	New Radio
NDP	Non-Dominant Penetration
O&M	Operations and Maintenance
PS	Packet Switched
PSL	Packet Switched Large packages dominating
PSS	Packet Switched Small packages dominating
QCI	QoS Class Identifier

QoS	Quality of Service
RA	Radio Access
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
RU	Rural
SEE	Site Energy Efficiency
SI	Site Infrastructure
SINR	Signal to Interference plus Noise Ratio
SU	Suburban
TCO	Total Cost of Ownership
TE	Telecommunication Equipment
TMA	Tower Mounted Amplifier
TTI	Transmission Time Interval
U	Urban
UE	User Equipment
UE-BS	User Equipment to Base Station
UL	Uplink
UMTS	Universal Mobile Telecommunications Service
UN	United Nations
URLLC	Ultra-Reliable Low Latency Communication
UTRAN	UMTS Terrestrial Radio Access Network
VNF	Virtualized Network Function
VoLTE	Voice over LTE

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 BSs;
  • Medium range BSs;
  • Local area BSs;
  • Home BSs;

  NOTE – Home BSs (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);
– Multiaccess EDGE equipment
– Backhaul (BH) equipment required to interconnect the BS used in the assessment with the core network;
– RC;
– Gateways to connect to the cloud.

Power consumption and energy efficiency measurements of individual mobile network elements are described in several standards (e.g., [b-ETSI ES 202 706-1] and [b-ETSI TS 102 706-2] for radio BSs). This Recommendation describes the energy consumption (EC) and mobile network (MN) energy efficiency measurements in operational networks.

As a comprehensive and detailed EC 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 a 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: an RC, 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 BSs or heterogeneous networks or what is actually implemented in real-world networks. Figure 1 shows a sub-network's general layout.

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

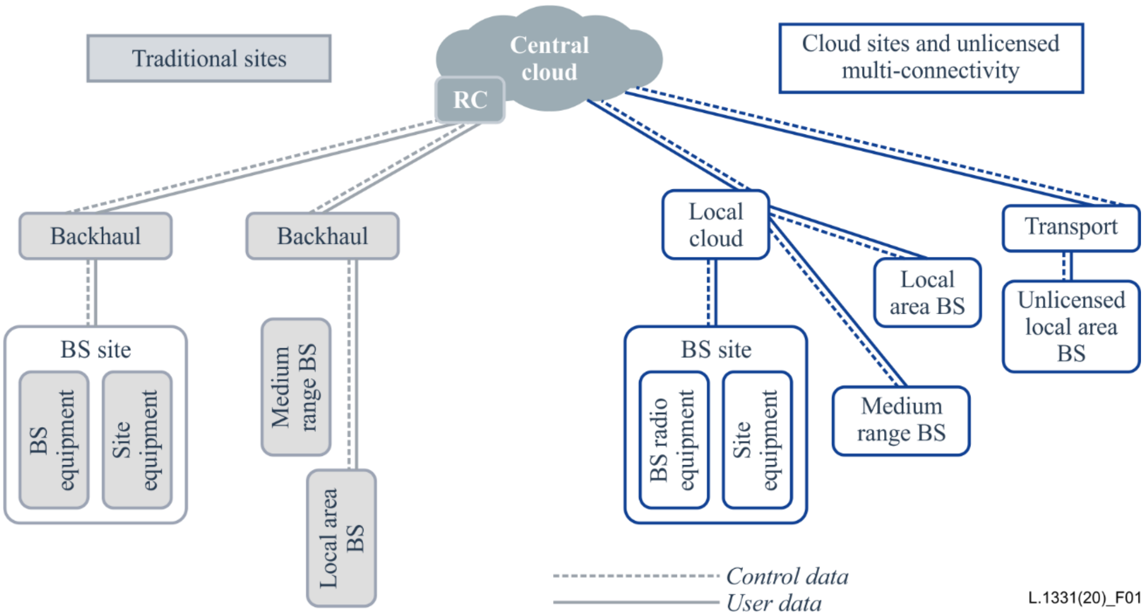

Figure 1 – Network under test definition

The functions outlined in Figure 1 could also be implemented in a cloud radio access network (CRAN).

The generic layout design for the cloud sites is defined in Figure 2.

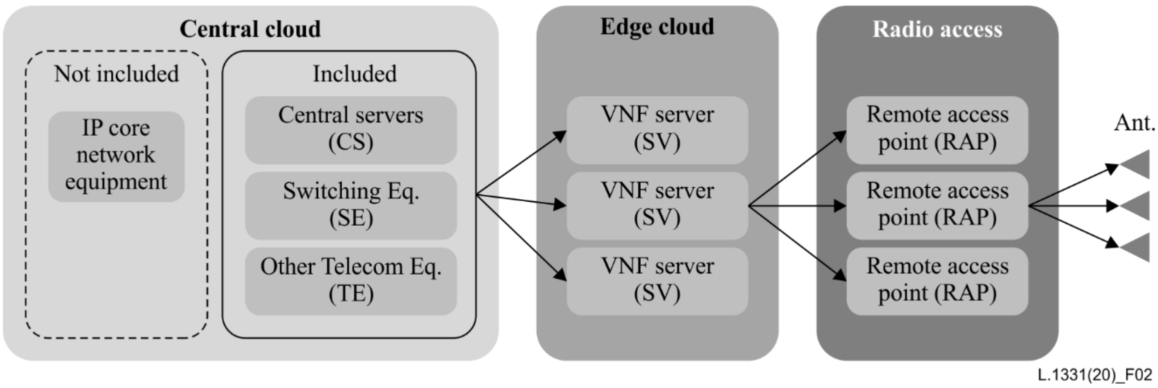

Figure 2 – Generic CRAN architecture layout

The RA domain consists of the remote access points (RAPs) dedicated to the CRAN under investigation. A typical RAP would include the radio, baseband and optical transport equipment. It performs real-time eNB tasks (e.g., scheduler) which is installed near the transmitting antennas.

The edge cloud (EDC) domain consists of small datacentres dedicated to telecommunication functions, including virtualized network function (VNF) servers used by the CRAN under investigation. A typical EDC datacentre would perform non-real-time eNB tasks, such as administration and operations and maintenance (O&M).

The central cloud (CC) domain consists of a multiserver datacentre (DC) including central servers (CSs), switching equipment (SE) and other telecommunication equipment (TE) if needed. CC datacentres are usually very far from most of the served EDC.

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 (EC, 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 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 (DV)	As defined in clause 7.3
1	Coverage area	As defined in clause 8.3.3
1	Latency	As defined in clause 7.3.3
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	Additional classification 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 demography, topography and climate zones as described in the following clauses.

The environmental classes used for network classification are: demography, topography and climate zones and are described in clauses 6.3.2 to 6.3.4.

6.3.2 Demography

For the test purposes defined in this Recommendation, the mobile network shall be 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)
DU	20 000	>10 000
Urban (U)	2 000	1 000–10 000
Suburban (SU)	300	200–1 000

Table 2 – Sub-network demography classes

Demography class	Typical population density (inhabitants/km^2)	Population range (inhabitants/km^2)
Rural (RU)	30	20–200
Unpopulated	0	<20

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

6.3.3 Topography

The topography classes reported in Table 3 shall be used.

Table 3 – Sub-network topography classes

Topography classification		Examples
ETSI class	Median slope	
1 Flat (FAO 1-3)	0–5%	Denmark, Netherlands
2 Rolling (FAO 4-6)	>5–30%	France, Italy
3 Mountainous (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-1].

6.3.4 Climate zones

The climate zones reported in Table 4 have been identified.

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*	
	Bs	Steppe climate
	Bs	Desert
C: Temperate	*Average temperature of the coldest month < 18°C and > −3°C, and average temperature of the warmest month > 10°C*	

Table 4 – Sub-network climate classes

Climate class	Subclass	Explanation
	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 the 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 the warmest month > 0°C
	Ef	No month with temperature > 10°C

The above reported climate classification is based on the FAO Koeppen classification [b-FAO-2].

It is recommended to use the five main classes A to E; the indication of the subclasses is optional.

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 lists the classification based on the penetration rate and Table 6 lists the classification based on data volume (DV) thresholds.

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, >80% of packages are small
Packet switched large (PSL)	PS – large packages dominating	>50% of data volume is PS, <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 (ECMN) is the sum of the energy consumption of each piece of equipment included in the MN under investigation (see clause 6). The network EC is measured according to the assessment process defined in clause 8.3.1 such that individual metric values are provided per radio access technology (RAT) and per MNO.

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

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 (including transport);
- *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;
- *CC* is the central cloud, LC the local cloud entities, as defined in Figure 1;
- *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;
- *m* is the number of small cells, local cells in 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 the one which is assessed, only a 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 EC impact of local factors (e.g., location specific site equipment), it is recommended to report, into the parameter EC_{SIi}, the measurement of the site equipment consumption into two classes:

1) information communications technology (ICT) equipment (equipment directly needed to perform the telecommunication 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 telecommunication service, such as air-conditioning, backup 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 EC of the TE with reference to the total EC is introduced:

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

The above metric gives an indication of site energy efficiency (SEE) in terms of the fraction of energy used for actual TE (see Figure 3).

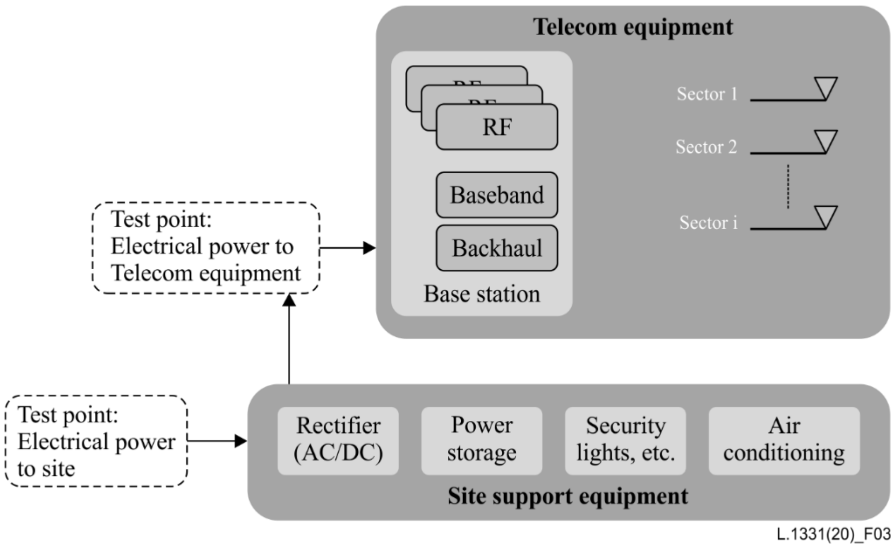

Figure 3 – Layout of a typical site to determine the SEE metric

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, BS 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 to 28 °C	IP23
B	−20 to 40 °C	IP45
C	−40 to 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 4 (where the notion of "extended telecommunication site" has been included to also include the on-site electricity generation and the "*" makes reference to the Telecommunication site as in Figure 3).

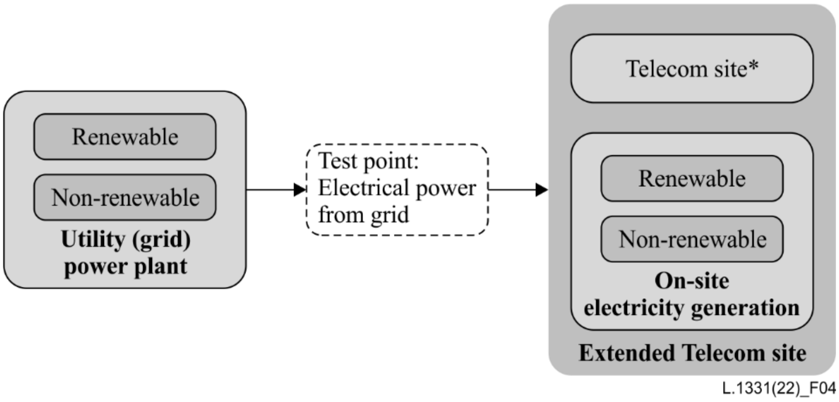

Figure 4 – Schematic representation of the energy sources for a site

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

– total electrical EC of the site;

– total electrical EC 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.

The EC of the central and local cloud is measured in Wh over the period T. For a virtualized environment, the measurement procedure for energy efficiency is described in the [b-ETSI EN 303 471].

7.3 Performance metrics

7.3.1 Capacity (data volume)

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 EC 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 such as 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 EC 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" means here all voice services, 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]). For 5G the DV can be derived from ETSI TS 128.552/TS128.554, by measuring amount of DL/UL PDCP SDU bits of the considered network elements over the measurement period.

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 expressed in bits.

7.3.2 Coverage area

Coverage area (CoA_{MN}) is also considered 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 expressed in m^2.

7.3.3 Latency

Latency is considered additionally for MN where ultra-reliable low latency communication (URLLC) use cases predominate. Latency is measured in [ms]. Within the definition of E2EE latency, only the user plane latency is considered, being more relevant in terms of application performance of the network under test. The definitions of latency are based on [ITU-R M.2410].

For measurement purposes the UP latency is:

$$T_{e2e;MN} = 2 * (T_r + T_b + T_c + T_t) \quad (5)$$

where:

- $T_{e2e,MN}$ is the end-to-end user plane latency.
- T_r is the latency introduced by the radio part, according to Figure 5, namely the packet transmission time between BSs and UEs, and is mainly due to physical layer communication.
- T_b is the latency introduced by the backhaul part, according to Figure 5, namely the time for building connections between BSs and the core network.
- T_c is the latency introduced by the core part, according to Figure 5, namely the processing time in the core network.
- T_t is the latency introduced by the transport part, according to Figure 5, namely the delay for the data to be sent from the core network to the Internet/cloud.

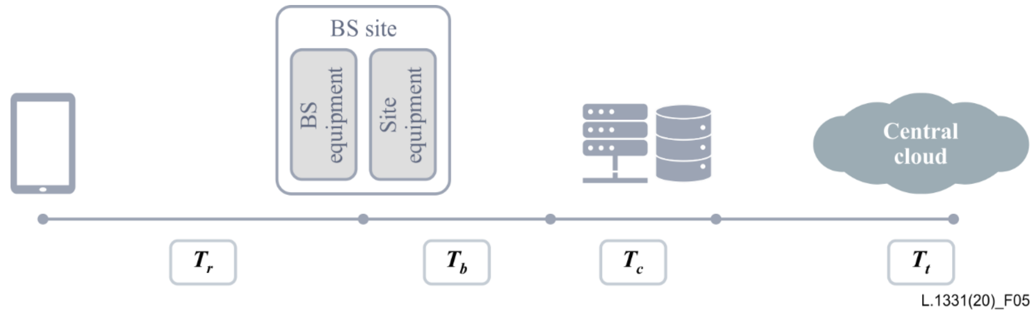

Figure 5 – Definition of the end-to-end user plane latency components

7.3.4 Massive machine type networks

The number of subscribers registered to the network is the metric used in case of MMTC networks or network slices.

7.4 Mobile network energy efficiency metrics

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

$$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}} \tag{6}$$

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 EC when assessed for 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:

$$EE_{MN,CoA} = \frac{\mathrm{CoA\_des_{MN}}}{EC_{MN}} \tag{7}$$

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

Latency based metric is the inverse ratio of the end-to-end user plane latency and the energy consumed by the MN.

$$EE_{MN,L} = \frac{1}{T_{e2e,MN} * EC_{MN}} \tag{8}$$

where $EE_{MN,L}$ is expressed in ms^{-1}/J.

In case of MMTC networks the metric for EE is as follows:

$$EE_{MN,MMTC} = \frac{N_{MMTC}}{EC_{MN}} \tag{9}$$

For networks with Network Slicing (NS) functionalities the EE is measured as follows (ETSI TS 128.554[14]):

$$Generic\ network\ slice\ EE\ KPI = \frac{Performance\ of\ network\ slice\ (P_{ns})}{Energy\ Consumption\ of\ network\ slice\ (EC_{ns})} \tag{10}$$

where the performance P_{ns} is related to the type of NS implemented in the network:

$$P_{ns} = DV_{mn} \text{ for the eMBB NS type}$$

$$P_{ns} = \frac{1}{T_{e2e,MN}} \text{ for the URLLC NS type}$$

$$P_{ns} = N_{MMTC} \text{ for the MMTC NS type}$$

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 *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 EC 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 measurement time, which 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 EC, following the requirements set by [ES 202 336-12].

The EC_{MN} is based on site granularity and therefore includes all the equipment installed in the MNO sites (including the network controllers whenever applicable). The EC_{MN} shall be differentiated per MNO providing service to the MN; in cases of shared infrastructure the EC_{MN} of the shared sites shall be computed per MNO sharing those sites, referring to the commercial agreements or best practices between MNOs. 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 EC 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 202 706-1].

The frequency of reporting shall be determined to guarantee the most accurate estimation of the consumption per RAT and per MNO and should take into account the energy provider billing procedures, the MN performance assessment process and the MN integrated measurement system (if available and if compliant with [ETSI ES 202 336-12]). The choice of the reporting frequency shall be documented in the assessment report.

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 the overall amount of data transferred to and from the users connected to the MN under test. Data volume is measured in an aggregated way for each RAT present in the MN.

For CS traffic (e.g., CS voice or VoLTE), the data volume is considered 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:

$$Call\ Success\ Rate = (1 - dropping\ rate) \times 100\ [\%] \quad (11)$$

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

$$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \quad (12)$$

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, requiring the usage of probes, is out of scope of this Recommendation.

NOTE 2 – As soon as the minimization of drive test (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]).

8.3.3 Determination of coverage area

8.3.3.1 Introduction

The coverage area is closely linked 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.

In order to have simple tests, 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 licence 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 highlights possible drops in network performances due, for example, to coverage issues (e.g., inside buildings), load congestion or significant interference effects.

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 licence agreements. This area might be not completely covered by the network. A licence 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 licence agreement or similar, is delivered. The area (sometimes referred to as "best server" area), is based on BS 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. Only the footprint of the building is considered the in-building area (e.g., in multistory buildings), rather than 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 factor measures the performances of the network within the actually covered fraction of the planned total coverage area. UE 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 QoS definitions.

A coverage map based on signal quality, such as the signal to interference plus noise ratio (SINR) as shown in Figure 6, could be used to determine the fraction of the total area where a signal quality above a certain minimum value is achieved. However, such maps require a large number of field measurements.

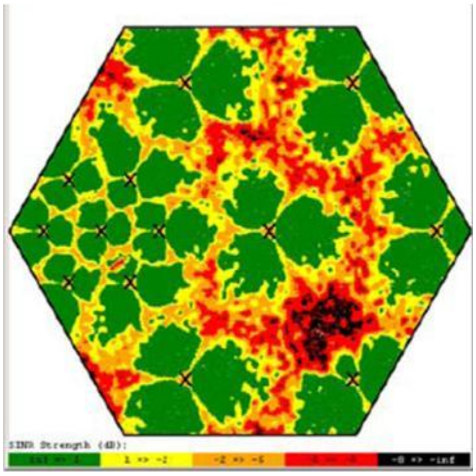

Figure 6 – Typical SINR distribution of a mobile network

For the sake of an energy efficiency assessment, it is not required to have knowledge of detailed network conditions such as actual coverage gap locations. From an energy efficiency assessment point of view, it is important to estimate the percentage of users/sessions or served users/sessions experiencing technical problems within the considered area.

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

The coverage quality factor shall be measured based on coverage failures reported by the appropriate network counters (see Tables 8 to 10):

$$CoA\_Qdes = 1 - \text{"percentage of users/sessions with coverage failure"} \qquad (13)$$

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:

$$CoA\_Qdes = (1 - \text{RRC setup failure ratio})\ (1 - \text{RAB setup failure ratio})\ (1 - \text{RAB release failure ratio}) \quad (14)$$

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 = (Σ_k Failed RRC connection establishment s_k)/(Σ_k attempted RRC connection establishment s_k);

– RAB setup failure ratio = (Σ_k RAB setup $failure_k$)/(Σ_k RAB setup $attempted_k$);

– RAB release failure ratio = (Σ_k RAB release $failure_k$)/(Σ_k RAB release $attempted_k$),

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

Tables 8, 9 and 10 report the measurement parameters required for coverage quality calculation. For LTE, see Table 8 (refer to [ETSI TS 132 425] for definition/source), for UMTS, see Table 9 (refer to [ETSI TS 132 405]) and for GSM, see Table 10 (refer to [ETSI TS 152 402]).

Table 8 – 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 9 – 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*, RAB.FailEstabCSQueuing.*sum*
	RAB setup for PS domain	RAB.FailEstabPSNoQueuing.*sum* RAB.FailEstabPSQueuing.*sum*
RAB setup attempts	RAB setup for CS domain	RAB.AttEstabCS.Conv.<U><D> RAB.AttEstabCS.Strm

Table 9 – Measurements parameters required for coverage quality calculations for UMTS

Parameter	Function	Counter name
		RAB.AttEstabCS.Intact RAB.AttEstabCS.Bgrd
	RAB setup for PS domain	RAB.AttEstabPS.Conv RAB.AttEstabPS.Strm.<U><D> RAB.AttEstabPS.Intact RAB.AttEstabPS.Bgrd
RAB release failures	RAB release for CS domain	RAB.FailRelCS.*sum*
	RAB release for PS domain	RAB.FailRelPS.*sum*
RAB release attempts	RAB release for CS domain	RAB.AttRelCS.*sum*
	RAB release for PS domain	RAB.AttRelPS.*sum*

Table 10 – 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:

$$\mathrm{CoA\_Qdes}_{\mathrm{MN}} = \sum\nolimits_{\mathrm{i}} 〚CoA\_Qdes〛\_(S\_i)\,\mathrm{DCA}_{\mathrm{S_i}} \,/ \sum\nolimits_{\mathrm{i}} \mathrm{DCA}_{\mathrm{S_i}} \qquad (15)$$

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 'designed coverage' area should be defined as the area where the signals from the cells located in that area are stronger than the signals from cells in adjacent areas. It holds true that:

$$CoA\_des_{MN} = \sum\nolimits_{\mathrm{i}} \mathrm{DCA}_{\mathrm{S_i}} \leq \mathrm{CoA\_geo} \qquad (16)$$

where:

S refers to the sites in the MN under measurement

i is an index spanning over the number of sites.

8.3.4 Measurement of latency

Latency is measured using the following step-based approach (only latency in MN is considered, not in direct communications modes):

- Step 0: Transmitter processing delay at BS;
- Step 1: Frame alignment;
- Step 2: Synchronization;

• Step 3: Number of transmission time intervals (TTIs) used for data packet transmission (unloaded condition is assumed);

• Step 4: Hybrid automatic repeat request (HARQ) retransmission (assuming 10% error probability);

• Step 5: Receiver processing delay in UE.

If the E2E latency KPI as defined in clause 6.3.1.0 of [ETSI TS 128 554] is available, that KPI shall be used for the metric of latency in this context.

8.3.5 Measurement of the number of subscribers

The N_MMTC is measured according to the definition reported in ETSI TS 128.554 clause 6.7.2.4.1.

9 Extrapolation for overall networks

9.1 Extrapolation approach

The energy efficiency (EE) measured according to clauses 7 and 8 can be extrapolated to larger networks, as shown in Figure 7. When such an extrapolation is performed, it shall follow 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.

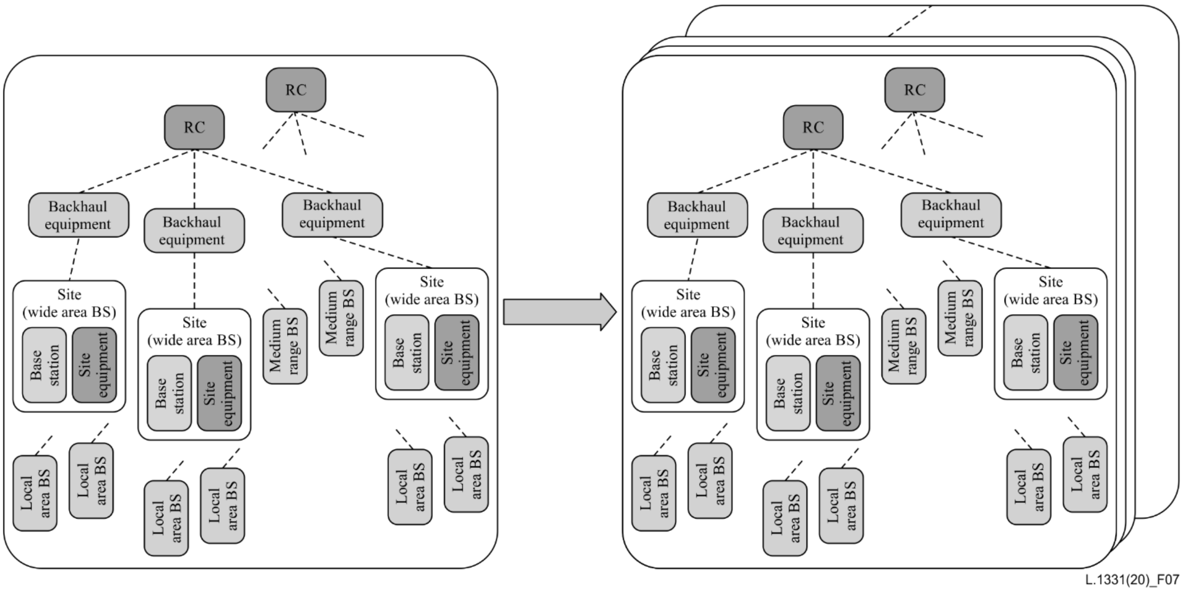

Figure 7 – Extrapolation from one sub-network to a set of sub-networks ("total" network)

The layout of the partial networks should be as reported in Figure 1, here simplified.

9.2 Extrapolation method

9.2.1 Introduction of extrapolation method

In case the overall/total area 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 area is completely known, then the extrapolation shall be made to achieve the information valid for the total network.

– The extrapolation procedure shall 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 shall be based on a demographic number of classes representing at least 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 topographical 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 topographical information can be found in the FAO Koeppen classification [b-FAO-2], which is used to classify the sub-network under test under a demographical class as in Table 4.

9.3 Extrapolation reporting tables

9.3.1 Introduction of extrapolation reporting tables

Table 11 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 a 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 11; 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:

$$EE_{class,av} = \frac{\sum_k EE_{MN,k}}{K} \quad (17)$$

where "class" stands for one of the demography classes (DU, U, SU, RU or unpopulated) and *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:

$$EE_{total} = \frac{\sum_m PofP_m EE_{class,av,m}}{\sum_m PofP_m} \quad (18)$$

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 (18).

9.3.2 Reporting extrapolation based on demography

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

Table 11 – Reporting extrapolation based on demography

Demography classification	Percentage of presence (PofP) in the total network area of the class	EE_{MN} in the class	
		$EE_{MN,DV}$	$EE_{MN,CoA}$
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, Table 12 and Table 13 are also to be reported.

9.3.3 Reporting extrapolation based on topography

The reporting extrapolation method based on topography is summarized in Table 12.

Table 12 – 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 (FAO 1–3)	$PofP_{Flat}$ [%]	$EE_{Flat,av}$	$EE_{Flat,av}$
2 Rolling (FAO 4–6)	$PofP_{Roll}$ [%]	$EE_{Roll,av}$	$EE_{Roll,av}$
3 Mountainous (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 13.

Table 13 – 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 the 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 on the network area under test

Table 14 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 CoA_des_{MN} is instead computed starting from the area covered by each site (per clause 8) and aggregating for all the sites in the network area under test.

For each site reported in Table 14, the details shall be included in Table 15. Table 16 reports the measurement results for each site.

Table 14 – Report of network area under test

Network area under test		
Demography class [DU, urban, suburban, rural, sparse] [Table 2]		
Topography class [Table 3]		
Climate zone [Table 4]		
Informative classification [Tables 5 and 6]		
Network area definition [by demography, by geography, by topology]		
	Number of inhabitants in the network area [estimate]	
	Network area dimensions [estimate, km^2]	

Table 14 – Report of network area under test

Network area under test		
	Number of sites in the network area [same RCs?]	
Type of sites in the network area		
	Number of wide area BS sites	
	Number of medium range BS sites	
	Number of other sites/equipment (local area BS, relay nodes, etc.)	
Site categorization		
	Number of sites in an MNO 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	
Multitechnology sites		
	Number of 2G-only sites	
	Number of 3G-only sites	
	Number of LTE-only sites	
	Number of 2G+3G sites	
	Number of 5G 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]	
	$EE_{MN, L}$ [ms^{-1}/J]	
	$EE_{MN,MMTC}$[J^{-1}]	
Energy efficiency top-down approach results (see note)		
NOTE – If any alternative EE approach has been conducted on the network under test (i.e., measuring the aggregated EC 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 15 – Report of sites under test

Site(s) under test in the network area (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" [wide area, medium range, other] In case of wide area, indicate number of sectors and carriers per sector	
	Site "technology" [2G, 3G, 2G+3G, LTE only, 2G+3G+LTE, 5G, other]	
	Site “MNOs” [single MNO, co-location, network sharing, other]	
Site and equipment age • *Initial commission date of the site* • *Commission date of the current equipment in the site*		
Temperature • *Average temperature [over period T]* • *Minimum temperature* • *Maximum temperature*	*Internal °C*	*External °C*
Environmental class Temp. range IC class (for each equipment in the site) *A 0 … 28* °C *B −20 … 40* °C *C −40 … 55* °C *IP class*		
Site infrastructure		
	Site location [local exchange premises, building, shelter, other]	
	Site composition	
	• Air conditioners	
	• Rectifiers/batteries	
	• Fixed network equipment consumption	
	• Other	

Table 15 – Report of sites under test

Site(s) under test in the network area (one table per site type to be measured in the network area)		
	Estimated percentage of infrastructure consumption in the site (EC_{si})	
EC of ICT equipment in the site [Wh]		
EC of all the support equipment in the site [Wh]		
Energy efficiency in the site equipment (Energy_ICTequipment / Energy_Total_network)		
– Total electrical energy supplied from the grid – Peak power delivered from the grid – Total site energy storage capacity – Peak shaving features available at the site		
Energy efficiency enhancement methods affecting the site equipment during the test		
Estimated percentage of presence of this site type in the network area		
Electricity sources used in the site		
	Electricity [%]	
	Generator set [%]	
	Solar [%]	
	Other renewables [%]	
	Others (indicate)	

10.4 Report of site measurement

Table 16 – 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	

Table 16 – Report of site measurement

Site measurement		
Temperature class and average temperature during the test		
EC in the site		
	Method of measurement [energy bills/counters, sensors, equipment information, other]	
	Measured energy consumption EC_{MN} [Wh or multiples]	
	• *weekly EC [per week data/graph]*	
	• *monthly EC [if T allows]*	
	• *yearly EC [if T allows]*	
Traffic offered in the site		
	Method of measurement [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]	
	CoA_Qdes:	
	• Failed RRC connection establishments • Attempted RRC connection establishments • RAB setup failure • RAB setup attempted • RAB release failure • RAB release attempted	
Latency of the site [ms^{-1}/J]		
	Latency	
Number of subscribers		
	Number of subscribers	
Site energy efficiency		
	Measured energy efficiency EE_{MN} [bit/J] and [m^2/J] and [ms/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 (composed by any RA network from 2G to 5G) 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, 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; 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 a 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 imposing rules in the deployment of networks, these constraints have to be taken into account when making any comparison. In such cases, only the comparison of networks under the same constraints are possible.

Regarding the time duration T of the measurement 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 need to be filled out completely in order for the measures to be considered as complying with this Recommendation. The test will be considered compliant if, when the measurements are carried out in very different scenarios, the scenarios are described in the tables, considering not only the final energy efficiency results but also how these results 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.

A possible application of this Recommendation could be to provide national authorities with a commonly accepted procedure to estimate the efficiency of a radio access technology or a set of RATs deployed by an MNO or a set of MNOs, at a national, regional or city level. This assessment can be performed as a standalone scenario to understand what efficiency is reasonably achievable, or it can be estimated towards a given threshold, to ensure that a minimum level of 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. 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 assess the benefits of the mentioned functionalities (when they 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 14 filled in with example data.

Table I.1

Network area under test (partial network #1)		
Demography class [DU, urban, suburban, rural, sparse] [Table 2]	DU	
Topography class [Table 3]	Flat	
Climate zone [4]	Temperate	
Informative classification [Tables 5 and 6]	DP, PSL	
Network area definition [by demography, by geography, by topology]	Demography	
	Number of inhabitants in the network area *[estimate]*	150 000
	Network area dimensions [estimate, km^2]	15 km^2

Table I.1

Network area under test (partial network #1)		
	Number of sites in the network area [same RCs?]	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
Multitechnology 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 fibres, 10 coppers
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 **(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" [wide area, medium range, other] In case of wide area, indicate number of sectors and carriers per sector	Wide area, 3 sectors 2 carriers each sector
	Site "technology" [2G, 3G, 2G+3G, LTE only, 2G+3G+LTE, other]	3G
	Site "MNOs" [single MNO, co-location, network sharing, other]	Single MNO
Site and equipment age *Initial commission date of the site* *Commission date of the current equipment in the site*		 2005/11/05 initial 2013/07/22 current equipment
Temperature *Average temperature [over period T]* *Minimum temperature* *Maximum temperature*	*Internal °C* *24.2 °C* *18.8 °C* *30.6 °C*	*External °C* *28.3 °C* *19.6 °C* *36.4 °C*
Site infrastructure		
	Site location [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 (one table per site type to be measured in the network area)		
EC of ICT equipment in the site [Wh]	1.5k	
EC 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 – Peak power delivered from the grid – Total site energy storage capacity – Peak shaving features available at the site	To be determined	
Energy efficiency enhancement methods affecting the site equipment during the test	Traffic related power from 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 at 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		
EC in the site		

Table I.3

Site measurement		
	Method of measurement [energy bills/counters, sensors, equipment information, other]	Sensors
	Measured energy consumption EC_{MN} [Wh or multiples]	
	• *Weekly EC [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 EC [if T allows]*	NA
	• *Yearly EC [if T allows]*	NA
Traffic offered at the site		
	Method of measurement [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 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 • Attempted RRC connection establishments • RAB setup failure • RAB setup attempted • RAB release failure • RAB release attempted	658 13 118 322 4998 294 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 time-frame (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.

$$EE_{total,DV} = \frac{PofP_{DU}*EE_{DU,av}+PofP_U*EE_{U,av}+PofP_{SU}*EE_{SU,av}+PofP_{Unp}*EE_{Unp,av}}{PofP_{DU}+PofP_U+PofP_{SU}+PofP_{Unp}} = \frac{42*200+20*40+15*8+13*2}{42+20+15+13} = 103.8\ b/J \quad (I.1)$$

$$EE_{total,CoA} = \frac{PofP_{DU}*EE_{DU,av}+PofP_U*EE_{U,av}+PofP_{SU}*EE_{SU,av}+PofP_{Unp}*EE_{Unp,av}}{PofP_{DU}+PofP_U+PofP_{SU}+PofP_{Unp}} = \frac{42*2,7+20*19+15*38+13*115}{42+20+15+13} = 28.4\ m^2/MJ \quad (I.2)$$

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).

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