International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

L.1330

(03/2015)

SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Energy efficiency measurement and metrics for telecommunication networks

Recommendation ITU-T L.1330

ITU International Telecommunication Union

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Summary

Recommendation ITU-T L.1330 provides a set of metrics for the assessment of energy efficiency (EE) of telecommunication (TLC) mobile networks, together with proper measurement methods. Such metrics are of extremely high importance to operators, given that the optimization of the energy performance of a single piece of equipment does not guarantee the overall maximum energy efficiency of a complex network formed by several interconnected equipments. Hence, through the metrics reported in this Recommendation, a better comprehension of network energy efficiency will be gained, not only for "total" networks, but also for "partial" networks, definable through either geographic or demographic boundaries.

In a future step, energy efficiency of TLC fixed networks will be provided.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1330	2015-03-01	5	11.1002/1000/12430

Keywords

Energy efficiency, metrics, networks.

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* 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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Introduction

Recommendation ITU-T L.1330 provides a set of metrics for the assessment of energy efficiency (EE) of telecommunication (TLC) mobile networks, together with proper measurement methods. Such metrics are of extremely high importance to operators, given that the optimization of the energy performance of a single piece of equipment does not guarantee the overall maximum energy efficiency of a complex network formed by several interconnected equipments. Hence, through the metrics reported in this Recommendation, a better comprehension of network energy efficiency will be gained, not only for "total" networks, but also for "partial" networks, definable through either geographic or demographic boundaries.

This Recommendation was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published respectively by ITU and ETSI as Recommendation ITU-T L.1330 and ETSI Standard ETSI ES 203 228, which are technically equivalent.

Recommendation ITU-T L.1330

Energy efficiency measurement and metrics for telecommunication networks

1 Scope

This Recommendation aims to define the topology and level of analysis necessary to assess the energy efficiency (EE) of mobile networks. Within the scope of this Recommendation are the radio access parts of the mobile network, namely: radio base stations, backhauling systems, radio controllers and other infrastructure radio site equipment. The technologies covered are: global system for mobile communications (GSM), universal mobile telecommunications communications (UMTS) and long-term evolution (LTE) (including LTE advanced (LTE-A)). In particular, this Recommendation defines metrics for mobile network energy efficiency and methods for assessing (and measuring) energy efficiency in operational networks. The purpose of this specification is to allow better comprehension of network energy efficiency.

This Recommendation deals with both homogeneous and heterogeneous "networks" and considers networks whose size and scale could be defined by topologic, geographic or demographic boundaries. For networks defined by topologic boundaries, a possible example of a network consists of a control node (whenever applicable), its supported access nodes, as well as its related network elements. Networks could also be defined by geographic boundaries, such as citywide, national or continental networks or by demographic boundaries, such as urban or rural networks.

This specification applies to the so-called "partial" networks where energy efficiency is measured in a standardized way. This specification extends the measurements in partial networks to wider so-called "total" network energy efficiency estimations (e.g., the network in a geographic area, the network in an entire country, the network of a mobile network operator (MNO)).

Terminal (end-user) equipment is outside the scope of this Recommendation and thus, 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.1310] Recommendation ITU-T L.1310 (2014), *Energy efficiency metrics and measurement methods for telecommunication equipment*.

[ETSI TS 123 203] ETSI TS 123 203 V12.6.0 (2014), *Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Policy and charging control architecture (3GPP TS 23.203 version 12.6.0 Release 12)*.

[ETSI TS 125 104] ETSI TS 125 104 V12.4.0 (2014), *Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104)*.

[ETSI TS 132 405] ETSI TS 132 405 V12.0.0 (2014), *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 12.0.0 Release 12).

[ETSI TS 132 412] ETSI TS 132 412 V12.0.0 (2014), *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 12.0.0 Release 12).*

[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 V12.5.0 (2014), *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 12.5.0 Release 12).*

[ETSI TS 136 314] ETSI TS 136 314 V12.0.0 (2014), *LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Layer 2 – Measurements (3GPP TS 36.314 version 12.0.0 Release 12).*

[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

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 backhaul equipment: Equipment used to connect base stations (BSs) to the core network, or to other BSs (such as X2 in LTE).

3.2.2 base station (BS): A generic term used for a network component which serves one or more cells and interfaces the user terminal (through air interface) and a radio access network infrastructure.

3.2.3 distributed RBS: A radio BS (RBS) architecture which contains remote radio heads (RRHs) close to the antenna element and a central element connecting BS to network infrastructure.

3.2.4 energy: Capacity for doing work; having several forms that may be transformed from one to another, such as thermal (heat), mechanical (work), electrical or chemical, expressed in Joules. For the purpose of this Recommendation, energy will be expressed in Watt-hours (Wh) or kilo Watt-hours (kWh).

3.2.5 energy efficiency (EE): The relation between the useful output and energy/power consumption.

3.2.6 energy saving feature: A feature which contributes to decreasing energy consumption as compared to the case when the feature is not implemented.

3.2.7 integrated BS: A BS architecture in which all BS elements are located close to one another for example in one or two cabinets.

NOTE – The integrated BS architecture may include tower mount amplifier (TMA) close to antenna.

3.2.8 mobile network (MN): A set of equipment from the radio access network or subnetwork that are relevant for the assessment of energy efficiency.

3.2.9 mobile network coverage energy efficiency: The ratio between the area covered by the network in the mobile network under investigation and the energy consumption.

3.2.10 mobile network data energy efficiency: The ratio between the performance indicator based on data volume and the energy consumption when assessed during the same time frame.

3.2.11 mobile network energy consumption: The overall energy consumption of equipment included in the MN under investigation.

3.2.12 mobile network energy efficiency: The energy efficiency of a mobile network.

3.2.13 mobile network operator (MNO): An operator that manages one or more mobile networks.

3.2.14 mobile network operator penetration ratio: The percentage of traffic served by a mobile network operator in the area where it is active.

3.2.15 mobile network performance delivered: The performance indicator of the MN under investigation, defined as the data volume delivered by the mobile network under investigation during the time frame of the energy consumption assessment.

3.2.16 power: The rate at which energy is transmitted. Power is measured in units of Watts.

3.2.17 power consumption: The power consumed by a device needed to achieve an intended application performance.

3.2.18 radio access network: A telecommunication network in which the access to the network (connection between user terminal and network) is implemented without the use of wires and is part of GSM/EDGE radio access network (GERAN), UMTS terrestrial radio access network (UTRAN) or evolved UMTS terrestrial radio access network (E-UTRA) networks defined by 3rd Generation Partnership Project (3GPP).

3.2.19 telecommunication network: A network operated under a license granted by a national telecommunications authority, which provides telecommunications between network termination points (NTPs).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3GPP	3rd Generation Partnership Project
BS	Base Station
BH	Backhaul
CoA	Coverage Area
CR	Coverage Ratio
CS	Circuit Switched
DCA	Designed Coverage Area
DP	Dominant Penetration
DU	Dense Urban
DV	Data Volume

ECA	Effective Coverage Area
EDGE	Enhanced Data rate GSM Evolution
EE	Energy Efficiency
FAO	Food and Agriculture Organization
GSM	Global System for Mobile communication
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MN	Mobile Network
MNO	Mobile Network Operator
MP	Minor Penetration
NDP	Non-Dominant Penetration
O&M	Operation and Maintenance
PS	Packet Switched
PSL	Packet Switched Large packets dominating
PSS	Packet Switched Small packets dominating
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RAT	Radio Access Technology
RC	Radio Controller
RRC	Radio Resource Control
RRH	Remote Radio Head
RU	Rural
SCH	Signalling Channel
SINR	Signal to Interference plus Noise Ratio
SU	Suburban
SW	Software
TCH	Traffic Channel
U	Urban
UE	User Equipment
UTRAN	UMTS Terrestrial Radio Access Network

5 Conventions

None.

6 Network under test definition

6.1 Introduction

The mobile radio access network under investigation shall include all the equipment necessary to run a radio access network (RAN) or subnetwork. Equipment to be included in the mobile network (MN) under investigation follows:

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

NOTE – Home BSs (and WiFi access points) are not dealt with in this Recommendation version, but are being considered for a future version.

– 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 (EE) measurements of individual mobile network elements are described in several standards (e.g., [ITU-T L.1310] for radio base stations). This Recommendation however, describes energy consumption and MN energy efficiency measurements in operational networks.

As a complete and detailed energy consumption measurement of the entire network of a country or mobile network operator (MNO) is, in most cases, impossible or economically not viable, the total network is split into a small number of networks with limited size (i.e., "subnetworks").

These subnetworks are defined to represent some 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 subnetworks are defined by topologic, geographic or demographic boundaries. For networks defined by topologic boundaries, a possible example of a network covered by this Recommendation consists of a radio controller (whenever applicable), its supported access nodes as well as the related network elements. Networks could be defined by geographic boundaries, such as citywide, national or continental networks or could be defined by demographic boundaries, such as urban or rural networks.

The subnetworks analysed might consist of macro-only base stations, heterogeneous networks or what is actually implemented in real networks.

The tests defined in this Recommendation for subnetworks 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. The network under test definition is reported in Figure 1.

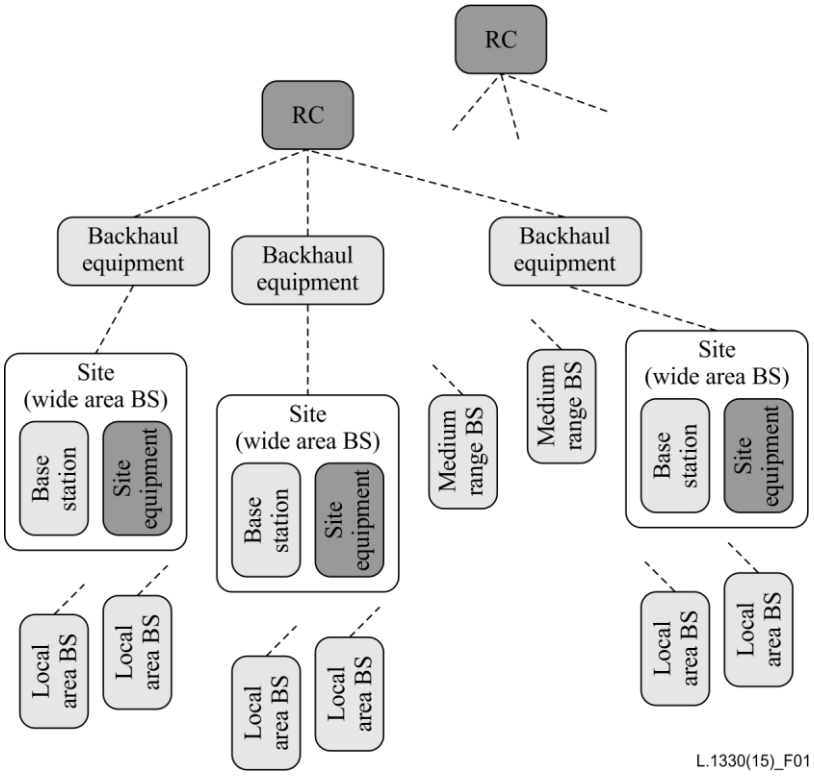

Figure 1 – Network under test definition

6.2 Test parameter categorization

Metrics used for the energy efficiency assessment of an MN 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 (i.e., energy consumption, delivered bits, coverage) to be used to calculate the energy efficiency.

The second category includes parameters that are not directly required in the energy efficiency calculation. These parameters describe the network characteristics, such as geographical conditions, population density, coverage area (CoA), targeted data rates, climate zones, etc., and are used to interpolate from the measured subnetwork to a larger network as described in clause 9. These parameters can be used to interpret variations in energy efficiency results of different networks. Table 1 reports the test parameter categorization.

Table 1 – Test parameter categorization

Category	Parameter	Remarks
1	EC_{MN}	Measured network energy consumption
1	Capacity	As defined in clause 7.2
1	Coverage area	As defined in clause 8.2.3
2	Coverage ratio	As defined in clause 8.2.3
2	Demography	Population density as defined in clause 6.3.1
2	Topography	As defined in clause 6.3.2
2	Climate zones	As defined in clause 6.3.3
2	Informative classes	As defined in clause 6.3.4
2	CS/PS data ratio	Describes the fraction of circuit switched (CS) traffic vs. packet switched (PS) traffic in the network

6.3 Network classification

To allow an extrapolation from the measured subnetworks ("partial" networks) to a complete network ("total" or "overall" networks), the test areas shall be classified into different categories as defined by network classification.

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

6.3.1 Demography

For the test purpose defined in this Recommendation, the MN shall be split into domains depending on population density. The following population density values per domain categories shall be used, as reported in Table 2.

Table 2 – Subnetwork demography classes

Demography class	Typical population density [inhabitants/km²]	Population range [inhabitants/km²]
Dense urban (DU)	20 000	> 10 000
Urban (U)	2 000	1 000 – 10 000
Suburban (SU)	300	200 – 1 000
Rural (RU)	30	20 – 200
Unpopulated	0	< 20
Some references to databases where the demography distribution classes are reported can be found in [b-EU Eurostat], [b-UN Demography] and [b-USA Demography]		

6.3.2 Topography

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

Table 3 – Subnetwork topography classes

Proposed system		Examples
Topography 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

The above information is from the median slope gradient class world map ([b-FAO Topography]).

6.3.3 Climate zones

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

Table 4 – Subnetwork climate classes

Climate class	Sub-class	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
	BW	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 ten times as much precipitation in wettest month of summer as in driest month of winter
	Cs	Summer dry season, at least three times as much rain in wettest month of winter as in driest month of summer, the latter having less than 30 mm precipitation
	Cf	At least 30 mm precipitation in the driest month, difference between wettest month and 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, difference between wettest month and driest month less than for Cw and Cs
	Dw	At least 10 times as much precipitation in wettest month of summer as in 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 FAO Koeppen classification ([b-FAO Climate]). The indication based on the five main classes A to E is mandatory; the subclasses are optionally indicated.

6.3.4 Informative classification classes

In order to properly select the subnetwork operators penetration ratio and data traffic types could be reported for information. Table 5 reports the classification based on penetration classes, Table 6 reports the classification based on data volume (DV) classes.

Table 5 – Subnetwork 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 – Subnetwork data volume classes

Symbol	Traffic Class	Specific threshold
CS	CS dominating	> 50% of data volume is CS
PSS	PS – small packets dominating	> 50% of data volume is PS > 80% of packets are small
PSL	PS – large packets dominating	> 50% of data volume is PS < 80% of packets are small

7 Metrics for energy efficiency assessment

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

7.1 Energy consumption metrics

The mobile network energy consumption (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 operator.

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

where:

EC is energy consumption

BS refers to the base stations in the MN under measurement

BH is the backhaul providing connection to the BSs in the MN under measurement

SI is the site infrastructure (rectifier, battery losses, climate equipment, tower mount amplifier (TMA), tower illumination, etc.)

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.

The energy sources available in the sites (power grid, genset, etc.) shall be reported in the tables of clause 10.

NOTE 2 – power generation is not part of MN energy efficiency, but reported for information, for use in total cost of ownership (TCO) and greenhouse gas (GHG) analyses.

7.2 Performance metrics

The MN performance metrics are derived from parameters of the MN under investigation (see clause 6) relevant for energy efficiency, in particular the total data volume (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 MN 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 formula (1).

For circuit switched services such as voice, $DV_{MN\text{-}CS}$ is defined as the data volume delivered by the equipment of the MN 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 defined in formula (1).

Note that here "circuit switched" refers to 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]) account also for quality of service (QoS) being reported in QoS class identifier (QCI) basis (see [ETSI TS 123 203]).

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

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

DV_{MN} is computed in bits.

The CoA_{MN} is also considered as a MN 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. CoA is computed in m^2.

7.3 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 frame.

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

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

The MN 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.

$$EE_{MN,CoA} = \frac{coverage\ area}{EC_{MN}} \quad (6)$$

where $EE_{MN,CoA}$ is expressed in m^2/J and EC_{MN} is the yearly energy consumption.

8 Measurement of energy efficiency

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

8.1 Time duration of the measurement

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

- weekly measurement: T equal to 7 days;
- monthly measurement: T equal to 30 days;
- yearly measurement: T equal to 365 days.

The minimum duration therefore, is one week; monthly and yearly measurements are extensions of the basic week test. For the CoA metric the energy consumption shall always be extrapolated to a one year time duration.

8.2 Measurement procedures

8.2.1 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 ([b-ETSI ES 202 336-12]). Moreover, sensors can be used to measure site and equipment energy consumption.

The EC_{MN} is based on site granularity and 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 the 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 in the site there are BS of different RATs the EC_{MN} shall be measured per 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 among each RAT proportionally to the configured RF power transmitted by each RAT; further details on the multi-RAT will be issued according to the development of multi-RAT measurements in [ITU-T L.1310].

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

NOTE – As soon as a mobile network integrated measurement system will be available [b-ETSI ES 202 336-12], 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.

8.2.2 Measurement of capacity

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

For 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 shall be measured in an aggregated way per RAT present in the MN and shall be measured referring to counters derived from vendor operation and maintenance (O&M) systems.

For CS traffic (e.g., CS voice or VoLTE), the data volume is considered as the number of minutes of communications during the observation period 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, i.e.,

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

The blocking rates are computed using the O&M counters. They are composed of traffic channel (TCH) and signalling channel (SCH) blocking rates:

$$1 - \text{blocking rate} = (1 - \text{TCH blocking rate})(1 - \text{SCH blocking rate}) \quad (8)$$

The dropping includes the intracell call failure and the handover failure:

$$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \quad (9)$$

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 need 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.

8.2.3 Determination of coverage area

Coverage area (CoA_{MN}) is subject to network planning and intended services delivered within a certain geographic 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 a different geographical area.

The coverage area shall be described by two distinct methods:

1) calculated coverage area derived from network design, planned service and geographical data;

2) measured network coverage based on user equipment (UE) reporting.

8.2.3.1 Geographic coverage area

The geographic network coverage area is the total two-dimensional area intentionally covered by the selected subnetwork. This area is defined by an MNO defined network service plan (minimum granted data rate/typical data rate, etc.) for the selected test area. The area is based on base station power, propagation conditions in the selected area and accepted outage criteria.

8.2.3.2 Coverage ratio/effective coverage area

The actual coverage area might differ from the originally planned coverage area (coverage holes within the considered area). The coverage ratio (CR) is a measure used to estimate the actual covered fraction of the planned total coverage area. User equipment reports such as signal strength and failed call attempts shall be used to more accurately determine the covered fraction. Drive tests and similar additional measurement campaigns should be avoided.

The coverage ratio / effective coverage area (ECA) shall be provided for network efficiency result evaluations. It is linked to network quality and has to be defined in relation to the QoS definitions.

A coverage map based on signal quality (signal to interference plus noise ratio (SINR)), such as the one shown in Figure 2, could be used to determine the fraction of the total area were a signal quality above a certain minimum value is achieved. However, such maps require a large number of measurements and drive tests.

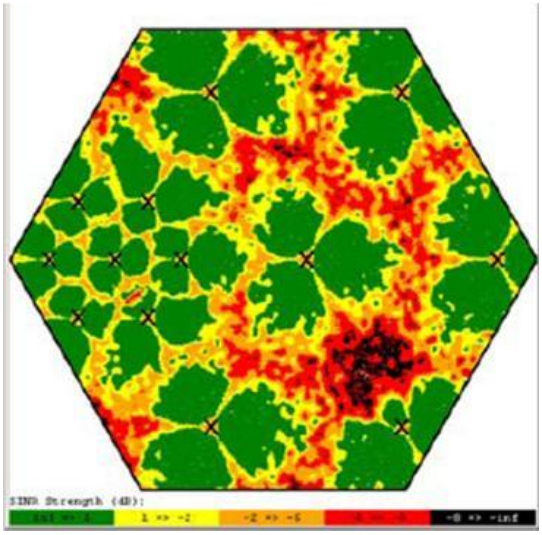

Figure 2 – Typical SINR distribution of a mobile network

For the sake of energy efficiency metrics it is not required to have the knowledge of the actual coverage hole locations. From an energy efficiency point of view, it is important to know how many users/sessions or served users/sessions experienced problems because of the lack of coverage 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 the coverage ratio.

The CR for a base station is defined:

Using the effective ECA and the designed coverage area (DCA) as:

$$CR = ECA/\ DCA \tag{10}$$

The effective coverage shall be measured based on coverage failures reported by the appropriate network counters:

$$CR = 1 - \text{"percentage of users/sessions with coverage failure"} \tag{11}$$

The following indicators shall be used to calculate the coverage failure:

- RRC set-up failure ratio (Call set-up failure ratio);
- RAB set-up 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 ratio. A handover drop can have multiple reasons (cell overload, UE speed, etc.). Furthermore, the handover drop rate depends on the network structure (number of neighbour cells). Its calculation requires several additional network parameters and complicates the data collection and analysis significantly. This factor is therefore omitted.

The coverage ratio is defined as follows:

CR = 1 – (1 – RRC set-up failure ratio) * (1 – RAB set-up failure ratio) * (1 – RAB release failure ratio)

The needed parameters are specified by 3rd Generation Partnership Project (3GPP) standards and the results can be obtained from network management and supervision.

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

RRC set-up failure ratio = failed RRC connection establishments/attempted RRC connection establishments.

RAB set-up failure ratio = RAB set-up failure/RAB set-up attempted.

RAB release failure ratio = RAB release failure/RAB release attempted.

Table 7 – Measurement parameters required for coverage ratio calculation (refer to [ETSI TS 152 402], [ETSI TS 132 405] and [ETSI TS 132 425] for 2G, 3G and 4G definition/source reference respectively)

Parameter	Function	Counter name
Failed RRC connection establishments	Radio resource control	RRC.ConnEstabFail.sum
Attempted RRC connection establishments	Radio resource control	RRC.ConnEstabAtt.sum
RAB set-up failure	Initial context set-up attempt	RAB.EstabInitFailNbr.sum
RAB set-up attempted	Initial context set-up attempt	ERAB.EstabInitAttNbr.sum
RAB release failure	RAB release	RAB.RelFailNbr.sum
RAB release attempted	RAB release	ERAB.RelAttNbr.sum

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

$$\mathrm{CR_{MN}} = \sum_{i,k} \mathrm{CR_{BS_{i,k}}} \mathrm{DCA_{BS_{i,k}}} \,/\, \sum_{i,k} \mathrm{DCA_{BS_{i,k}}} \qquad (13)$$

where:

BS refers to the base stations in the MN under measurement

i is an index spanning over the number of sites

k is the index spanning over the number of BSs in the *i*-th site.

9 Extrapolation for overall networks

The EE measured according to clauses 7 and 8 can be used to extrapolate to larger networks. When such an extrapolation is made, it shall be performed following the method presented in this clause.

The subnetwork data shall be extrapolated to overall/total networks according to demography, topography and climate classifications, as described in clause 6.

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

Figure 3 reports the logic of the extrapolation from one subnetwork to a set of subnetworks ("total" network).

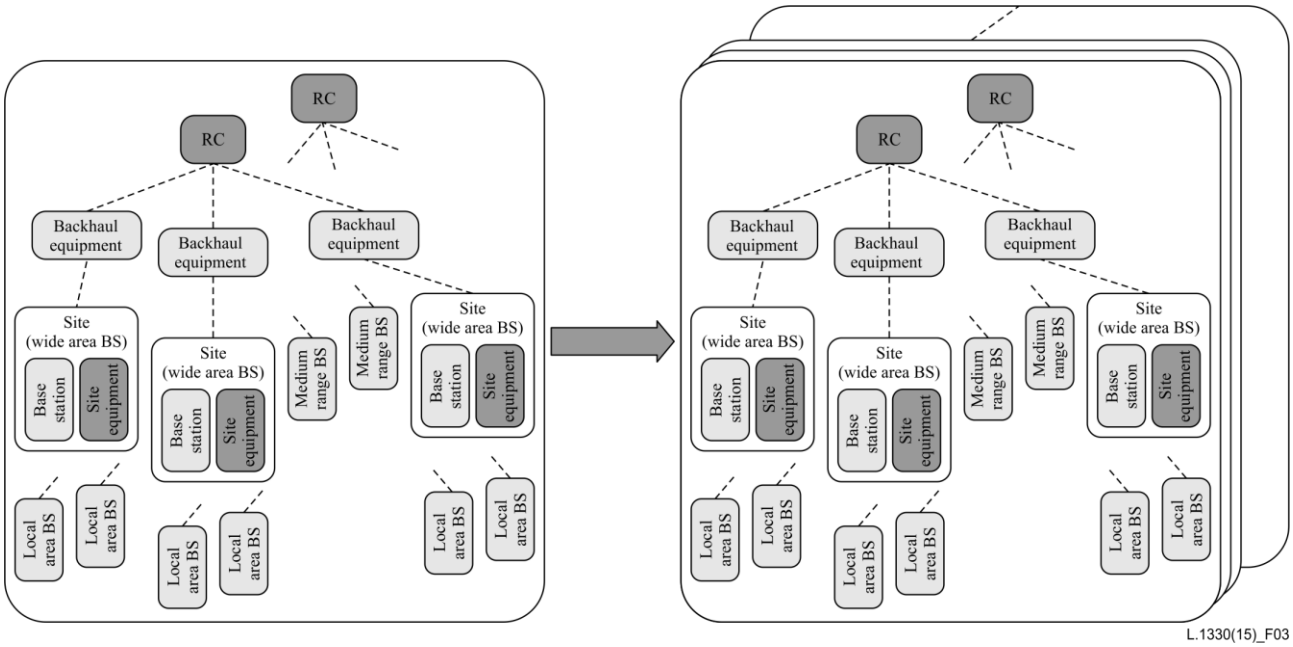

Figure 3 – Extrapolation from one subnetwork to a set of subnetworks ("total" network)

9.1 Extrapolation method

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

In such a case, it shall be indicated for each subnetwork what its perceptual recurrence is with respect to the global one, 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 entire total network.

The extrapolation procedure shall be based on the demography information classes as reported in Table 2. It is also optional to make 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 demography number of classes sufficient to represent at least the 75 per cent of the entire total network area demographical distribution.

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

9.1.1 Statistical information about demography

An example of demographical information for Europe, e.g., for population or population density, can be found in [b-EU Eurostat], to classify the subnetwork under test under a demography class as in Table 2.

An example referring to UN information is found in [b-UN Demography]. An example for USA information can be found in [b-USA Demography].

9.1.2 Statistical information about topography

An example of topography information can be found in [b-FAO Topography], to classify the subnetwork under test under a topography class as in Table 3.

9.1.3 Statistical information about climate zones

An example of climate information can be found in [b-FAO Climate], to classify the subnetwork under test under a climate class as in Table 4.

9.2 Extrapolation reporting tables

Table 8 indicates how to report the data for extrapolation towards total EE based on demography only. This is the mandatory approach when extrapolation data are computed. Not all of the classes shall be measured, but rather only those that allow coverage of at least 75 per cent of the entire demographical distribution of the total area under measurement.

For all the subnetworks, the results of EE are reported according to clause 10 tables and the relative class shall be indicated. For all the same class measurement an average of EE measurements shall be reported in Table 8; 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:

$$EE_{class,av} = \frac{\sum_k EE_{MN,k}}{K} \tag{14}$$

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 subnetworks per class.

The total EE shall be computed as a weighted sum of all the averages available, the weights are the percentage of each demography class versus the sum of the available classes' percentages. These percentages shall be derived from the information according to the examples of clause 9.1.

The total EE shall be then computed as follows:

$$EE_{total} = \frac{\sum_m PofP_m EE_{class,av,m}}{\sum_m PofP_m} \tag{15}$$

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

$EE_{class,av,m}$ is the m-th average as computed in equation (14).

9.2.1 Reporting extrapolation based on demography

In Table 8 the reporting extrapolation method based on demography is summarized.

Table 8 – Reporting extrapolation table 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		$EE_{total,DV}$	$EE_{total,CoA}$

The demography table is the mandatory extrapolation representation. In case the topography and climate zone classifications are also available for the subnetworks measured according to clause 10. Table 9 and Table 10 also have to be reported.

9.2.2 Reporting extrapolation based on topography

In Table 9 the reporting extrapolation method based on topography is summarized.

Table 9 – Reporting extrapolation table 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		$EE_{total,DV}$	$EE_{total,CoA}$

9.2.3 Reporting extrapolation based on climate zones

In Table 10 the reporting extrapolation method based on climate zones is summarized.

Table 10 – Reporting extrapolation table 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

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 10.1 to 10.3. Items in italics can be considered optional.

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

10.1 Report of network area under test

Table 11 reports the details of the network area under test, representing a subnetwork where the measurements are conducted. The network area is the area encompassing all the sites under measurement; the CoA is computed starting from the area covered by each site and aggregating for all the sites in the network area under test.

For each site reported in Table 11 the details shall be included in Table 12. Table 13 reports the measurements results for each site.

Table 11 – Report of network area under test

Network area under test		
Demography class [Dense urban, Urban, Suburban, Rural, Sparse] [Table 2]		
Topography class [Table 3]		
Climate zone [Table 4]		
Informative classification [Table 5, Table 6]		
Network area definition [by demography, by geography, by topology]		
	Number of inhabitants in network the area [estimate]	
	Network area dimensions [estimate, km^2]	

Table 11 – Report of network area under test

Network area under test		
	Number of sites in the *network* Area [same radio controller?]	
Type of sites in the *network* area		
	Number of wide area sites	
	Number of medium range sites	
	Number of other sites/equipment (local area, relay nodes, etc.)	
Sites 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	
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		
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		

10.2 Report of sites under test

Table 12 – 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	
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, 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*
Site infrastructure		
	Site location [local exchange premise, building, shelter, other]	
	Site composition	
	Air conditioners	
	Rectifiers/batteries	
	Fixed network equipment consumption	
	Other	
	Estimated percentage of infrastructure consumption in the site (EC_{si})	
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		

Table 12 – 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)		
	Electricity [%]	
	Genset [%]	
	Solar [%]	
	Renewables [%]	
	Others (indicate)	

10.3 Report of site measurement

Table 13 – Report of site measurement

Site measurement		
Measurement duration		
	Time duration of the measurement [T]	
	Measurement start date and time	
	Measurement finish date and time	
Temperature class and average temperature during the test		
Energy consumption in the site		
	Method of measurement [energy bills/counters, sensors, equipment information, other]	
	Measured energy consumption EC_{MN} [Wh or multiples]	
	Week energy consumption [per week data/graph]	
	Month energy consumption [if T allows]	
	Year energy consumption [if T allows]	
Traffic offered in the site		
	Method of measurement [operational counters, backhauling data, MDT, other]	
	Measured traffic volume DV [bit or multiples]	
	Week traffic [per week data/graph]	
	Month traffic [if T allows]	
	Year traffic [if T allows]	
Coverage of the site [data to be reported per RAT present in the site]		
	Designed coverage area CoA [km^2]	
	Coverage ratio [%]	
	Effective CoA [km^2]	
	Failed RRC connection establishments Attempted RRC connection establishments RAB set-up failure RAB set-up attempted RAB release failure	

Table 13 – Report of site measurement

Site measurement		
	RAB release attempted	
Site network 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

The specification is based on the mobile network area definition under test as described in clause 6, where measurements must be done according to the metrics defined in clause 7 and following the procedures 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 subnetwork results can be used for the assessment of larger networks, in particular when measurement over the entire total network is not possible due to its dimensions. In this case, the extrapolation approach defined in clause 9 shall be used.

Attention must be paid to the selection of the subnetworks where the measurements are made in order to ensure that the results are technically sound and, even if this is not the primary goal, comparable. 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 the purpose of this specification is not to make comparable what is not. However, 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 a radio access network.

An essential part of this common base method is represented by the tables in clause 10. Even in very different scenarios, these tables are to be filled in completely in order for the measurements to be accepted and to be standards-based. In such a way, even if the measurements are done in very different scenarios, the details of the scenarios are reported in the tables and, not only considering the final EE results but also how they were obtained, the tests will be considered standards compliant.

Appendix I

Implementation examples

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

Implementation examples

Considering the implementation guidelines reported in clause 11, a set of examples showing how to implement the energy savings (ES) is given in this appendix.

As an example, a possible application of this Recommendation is to provide national authorities a commonly accepted procedure to estimate, at national, regional or city level, the efficiency of a RAT or a set of RATs deployed by an MNO or a set of MNOs. This assessment can be stand-alone, in order to know what a reasonably achievable efficiency is, or it can be estimated towards a given threshold, to ensure that better efficiency is achieved (e.g., after the introduction of new ES 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 given timeframe. 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 time period, 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 the clause 10 tables is mandatory in order to check under which conditions the tests have been performed.

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

Examples of reporting data

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

Table I.1 is filled with example data.

Table I.1 – Example of reporting data

Network area under test (Partial network #1)		
Demography class [Dense urban, Urban, Suburban, Rural, Sparse] [Table 2]	Dense urban	
Topography class [Table 3]	Flat	
Climate zone [Table 4]	Temperate	
Informative classification [Table 5, Table 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 – Example of reporting data

Network area under test (Partial network #1)		
	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 sites	25
	Number of medium range sites	3
	Number of other sites/equipment (local area, 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 above.

Table I.2 – Example of a site in the partial network #1

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
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 – Example of a site in the partial network #1

Site(s) under test in the network area (one table per site type to be measured in the network area)		
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%
	Genset [%]	–
	Solar [%]	20%
	Other renewables [%]	–
	Others (indicate)	–

Table I.3 reports the measurement in the site described in the table above.

Table I.3 – Example of measurement in a site

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
Temperature class and average temperature during the test		
Class C, average internal temperature 24.2 °C		
Energy consumption in the site		
	Method of measurement [energy bills/counters, sensors, equipment information, other]	Sensors
	Measured energy consumption EC_{MN} [Wh or multiples]	
	Week energy consumption [per week data/graph]	*Introduce a graph of the kWh in the site, or a table of values, per week, according to the time granularity of the available data*
	Month energy consumption [if T allows]	N/A
	Year energy consumption [if T allows]	N/A
Traffic offered in the site		
	Method of measurement [operational counters, backhauling data, MDT, other]	Operational counters
	Measured traffic volume DV [bit or multiples]	
	Week traffic [per week data/graph]	*Introduce a graph of the Gb in the site, or a table of values, per*

Table I.3 – Example of measurement in a site

Site measurement		
		week, according to the time granularity of the available data
	Month traffic [if T allows]	NA
	Year traffic [if T allows]	NA
Coverage of the site [data to be reported per RAT present in the site]		
	Designed coverage area CoA[km^2]	0.5
	Effective coverage area CoA [km^2]	0.42
	Coverage ratio [%]	84%
	Failed RRC connection establishments Attempted RRC connection establishments RAB set-up failure RAB set-up attempted RAB release failure RAB release attempted	658 13 118 322 4 998 294 4 998
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]	N/A
	Yearly energy efficiency [if T allows]	N/A

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 one year as required for CoA EE metric.

Table I.4 – Example of computation of a global energy efficiency metric

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%	*N/A*	*N/A*
Overall/total EE		***103.8 b/J***	***28.4 m^2/MJ***

In order to better clarify the example in the table above 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).

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Printed in Switzerland
Geneva, 2015