ETSI ES 203 228 V1.4.1 (2022-04)

Environmental Engineering (EE);
Assessment of mobile network energy efficiency

Reference
RES/EE-EEPS48

Keywords
5G, access, base station, energy efficiency, GSM, LTE, mobile, network, radio, UMTS

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° w061004871

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The declarations pertaining to these essential IPRs, if any, are publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (https://ipr.etsi.org/).

Pursuant to the ETSI Directives including the ETSI IPR Policy, no investigation regarding the essentiality of IPRs, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

DECT™, **PLUGTESTS™**, **UMTS™** and the ETSI logo are trademarks of ETSI registered for the benefit of its Members. **3GPP™** and **LTE™** are trademarks of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners. **oneM2M™** logo is a trademark of ETSI registered for the benefit of its Members and of the oneM2M Partners. **GSM**® and the GSM logo are trademarks registered and owned by the GSM Association.

Foreword

This ETSI Standard (ES) has been produced by ETSI Technical Committee Environmental Engineering (EE).

The present document was developed jointly by ETSI TC EE and ITU-T Study Group 5. It will be published respectively by ITU and ETSI as Recommendation ITU-T L.1331 [i.4] and ETSI ES 203 228 (the present document), which are technically-equivalent.

Moreover the present document has been developed in collaboration with 3GPP SA5 and RAN3; GSMA has also given valuable suggestions and contributions.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

The present document deals with the definition of metrics and methods to measure 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 simplified approach is proposed for approximate energy efficiency evaluations and cannot be considered as a reference for planning evaluation purposes throughout the network operation process. The same approach was introduced also in ETSI TR 103 117 [i.1]; the measurements in testing laboratories of the efficiency of the Base Stations is the topic treated in ETSI ES 202 706 [i.2].

The present document provides also a method to extrapolate the assessment of energy efficiency to wider networks (clause 7).

The general outcome of the application of the method specified in the present document is based on the "Assessment report" introduced in clause 8. An example of application of the method is also given in annex A.

1 Scope

The present document is aimed at defining the topology and level of analysis to assess the energy efficiency of mobile networks. Within the scope of the present document there is the radio access part of the mobile networks, and namely there are radio base stations, backhauling systems, radio controllers and other infrastructure radio site equipment. The covered technologies are GSM, UMTS, LTE and 5G New Radio (NR). In particular the present document defines metrics for mobile network energy efficiency and methods for assessing (and measuring) energy efficiency in operational networks. The purpose of the present document is to allow better comprehension of networks energy efficiency, in particular considering the networks' evolution in different periods in time.

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

The present document deals with both a homogeneous and heterogeneous "network" considering a network 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 covered by the present document consists of a control node (whenever applicable), its supported access nodes as well as the related network elements. Networks could be defined by geographic boundaries, such as city-wide, national or continental networks and could be defined by demographic boundaries, such as urban or rural networks.

The present document applies to the so-called "partial" networks for which a measurement method is also recommended. The specification extends the measurements in partial networks to wider so-called "total" networks energy efficiency estimations (i.e. the network in a geographic area, the network in a whole country, the network of a MNO, etc.).

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

2 References

2.1 Normative references

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

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

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

[1] ETSI TS 125 104: "Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104)".

[2] ETSI TS 136 104: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104)".

[3] ETSI TS 132 425 (V12.0.0): "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)".

[4] ETSI TS 132 412 (V11.1.0): "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)".

[5] ETSI TS 123 203 (V12.7.0): "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)".

[6] ETSI TS 136 314: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Layer 2 - Measurements (3GPP TS 36.314)".

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

[8] ETSI TS 132 405 (V11.1.1): "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)".

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

[10] ISO/IEC 17025 (2005): "General requirements for the competence of testing and calibration laboratories".

[11] ETSI EN 303 471: "Environmental Engineering (EE); Energy Efficiency measurement methodology and metrics for Network Function Virtualisation (NFV)".

[12] Report ITU-R M.2410: "Minimum requirements related to technical performance for IMT-2020 radio interface(s)".

[13] ETSI TS 128 554: "5G; Management and orchestration; 5G end to end Key Performance Indicators (KPI) (3GPP TS 28.554)".

[14] ETSI TS 128 552 (V16.6.0): "5G; Management and orchestration; 5G performance measurements (3GPP TS 28.552 version 16.6.0 Release 16)".

2.2 Informative references

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

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

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

[i.1] ETSI TR 103 117: "Environmental Engineering (EE); Principles for Mobile Network level energy efficiency".

[i.2] ETSI ES 202 706 (all parts): "Environmental Engineering (EE); Measurement method for power consumption and energy efficiency of wireless access network equipment".

[i.3] ETSI GS NFV 003: "Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV".

[i.4] Recommendation ITU-T L.1331: "Assessment of mobile network energy efficiency".

[i.5] FAO Soils Portal.

NOTE: Available at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/.

[i.6] Jürgen Grieser, René Gommes, Stephen Cofield and Michele Bernardi: "Data sources for FAO worldmaps of Koeppen climatologies and climatic net primary production", 2006.

NOTE: Available at http://www.fao.org/nr/climpag/globgrids/KC_commondata_en.asp.

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

backhaul equipment: equipment used to connect base stations to the core network, or to other BSs (like X2 in LTE)

Base Station (BS): generic term used for network component which serves one cell or more cells and interfaces the user terminal (through air interface) and a radio access network infrastructure

distributed RBS: BS architecture which contains Remote Radio Heads (RRH) close to the antenna element and a central element connecting BS to network infrastructure

end-to-end latency: time that 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

Energy Efficiency (EE): relation between the useful output and energy/power consumption

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

integrated BS: BS architecture in which all BS elements are located close to each other for example in one or two cabinets

NOTE: The integrated BS architecture may include TMA close to antenna.

Mobile Network (MN): set of equipment from the radio access network or sub-network that are relevant for the assessment of energy efficiency

mobile network coverage energy efficiency: ratio between the area covered by the network in the Mobile Network under investigation and the energy consumption

mobile network data energy efficiency: ratio between the performance indicator based on Data Volume and the energy consumption when assessed during the same time frame

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

mobile network energy efficiency: energy efficiency of a mobile network

Mobile Network Operator (MNO): operator that manages one or more mobile networks

mobile network operator penetration ratio: percentage of traffic served by an MNO in the area where it is active

mobile network performance delivered: 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

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

radio access network: telecommunications network in which the access to the network (connection between user terminal and network) is implemented without the use of wires and that is part of GERAN, UTRAN or E-UTRA networks defined by 3GPP

Site Energy Efficiency (SEE): metric used to determine the energy efficiency of a telecommunication site

NOTE: SEE is defined by the ratio of "IT equipment energy" and "Total site energy", which generally includes rectifiers, cooling, storage, security and IT equipment. For datacentres, the "Total site energy" more globally includes building load, powering equipment (e.g. switchgear, uninterruptible power supply (UPS), battery backup), cooling equipment (e.g. chillers, Computer Room Air Conditioning unit (CRAC)) and IT equipment energy.

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

Virtualised Network Function (VNF): See ETSI GS NFV 003 [i.3].

3.2 Symbols

Void.

3.3 Abbreviations

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

3GPP	3G (mobile) Partnership Project
BH	Backhaul
BS	Base Station
CC	Central Cloud
CoA	Coverage Area
CoA_des	designated coverage area as designed by network planning
CoA_geo	total geographical area under investigation and within the operator's license agreement
CoA_Qdes	quality factor describing how well users are covered within the coverage area
CoA_{MN}	Coverage Area Mobile Network
CRAN	Cloud Radio Access Network
CS	Circuit Switched
CS/PS	Circuit Switched/Packet Switched
DC	Data Center
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
EC_{SI}	Energy Consumption of the Site
EDC	Edge Cloud
EDGE	Enhanced Data rates for GSM Evolution
EE_{MN}	Energy Efficiency of the Mobile Network
E-RAB	E-UTRAN Radio Access Bearer
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FAO	Food and Agriculture Organization
GERAN	GSM/EDGE Radio Access Network
GHG	GreenHouse Gas
GSM	Global System for Mobile communication
GSMA	GSM Association
HARQ	Hybrid Automatic Repeat Request
ICT	Information Communications Technology
IP	Ingress Protection
ITU	International Telecommunications Union

ITU-T	International Telecommunications Union - Telecommunication
KPI	Key Performance Indicator
LC	Local Cloud
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MJ	MegaJoule
MMTC	Massive Machine Type Communication
MN	Mobile Network
MNO	Mobile Network Operator
MP	Minor Penetration
NA	Not Applicable
NDP	Non Dominant Penetration
NR	New Radio
O&M	Operation & Maintenance
PDCP	Packet Data Control Protocol
PDF	Probability Distribution Function
PofP	Point of Presence
PS	Packet Switched
PSL	Packet Switched Large packages dominating
PSS	Packet Switched Small packages dominating
QCI	QoS Class Identifier
QoS	Quality of Services
RA	Radio Access
RAB	Radio Access Bearer
RAN	Radio Access Network
RAP	Radio Access Point
RAT	Radio Access Technology
RC	Remote Controller
RF	Radio Frequency
RNC	Radio Network Controller
RRC	Radio Resource Control
RRH	Remote Radio Head
RU	Rural
SDU	Service Data Unit
SE	Switching Equipment
SEE	Site Energy Efficiency
SI	Site Infrastructure
SINR	Signal to Interference plus Noise Ratio
SU	Sub Urban
TCO	Total Cost of Ownership
TE	Telco Equipment
TMA	Tower Mounted Amplifier
U	Urban
UE	User Equipment
UE-BS	User Equipment to Base Station
UL	UpLink
UMTS	Universal Mobile Telecommunication Service
UN	United Nations
UP	User Plane
URLLC	Ultra Reliable Low Latency Communications
USA	United States of America
UTRAN	UMTS Terrestrial Radio Access Network
VNF	Virtualised Network Function
VNFS	Virtualised Network Function Servers
X2	Interface allowing to interconnect eNBs with each other

4 Network under test definition

4.1 Introduction

The Mobile Network (MN) for Radio Access (RA) under investigation shall include all the equipment that is necessary to run a radio access network or sub-network. Equipment to be included in the Mobile Network under investigation:

- Base Stations (see ETSI TS 125 104 [1] and ETSI TS 136 104 [2]):
  - Wide area BS.
  - Medium range BS.
  - Local Area BS.
  - Home BS.

NOTE: Home BS (and Wi-Fi access points) are not dealt with in the present document, being possibly considered for future versions.

- Site equipment (air conditioners, rectifiers/batteries, fixed network equipment, etc.).
- Multi-Access EDGE equipment.
- Backhaul equipment required to interconnect the BS used in the assessment with the core network.
- Radio Controller (RC).
- Gateways to connect to the Cloud.

Power consumption and energy efficiency measurements of individual mobile network elements are described in several standards (for example ETSI ES 202 706-1 and ETSI ES 202 706-2 [i.2] for radio base stations). The present document describes energy consumption and MN energy efficiency measurements in operational networks.

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

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

- capacity limited networks representing urban and dense urban networks;
- sub-urban networks with high requirements for coverage and capacity;
- rural 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, a possible example of a network covered by the present document 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 city-wide, national or continental networks and could be defined by demographic boundaries, such as urban or rural networks.

The sub-networks analysed might consist of macro-only base stations or heterogeneous networks or whatever is actually implemented in real networks. A description of the sub-network general layout is represented in the figure 1.

The tests defined in the present document for sub-networks provide the basis to estimate energy efficiency for large networks of one MNO or within an entire country, applying the extrapolation methods described in clause 7.

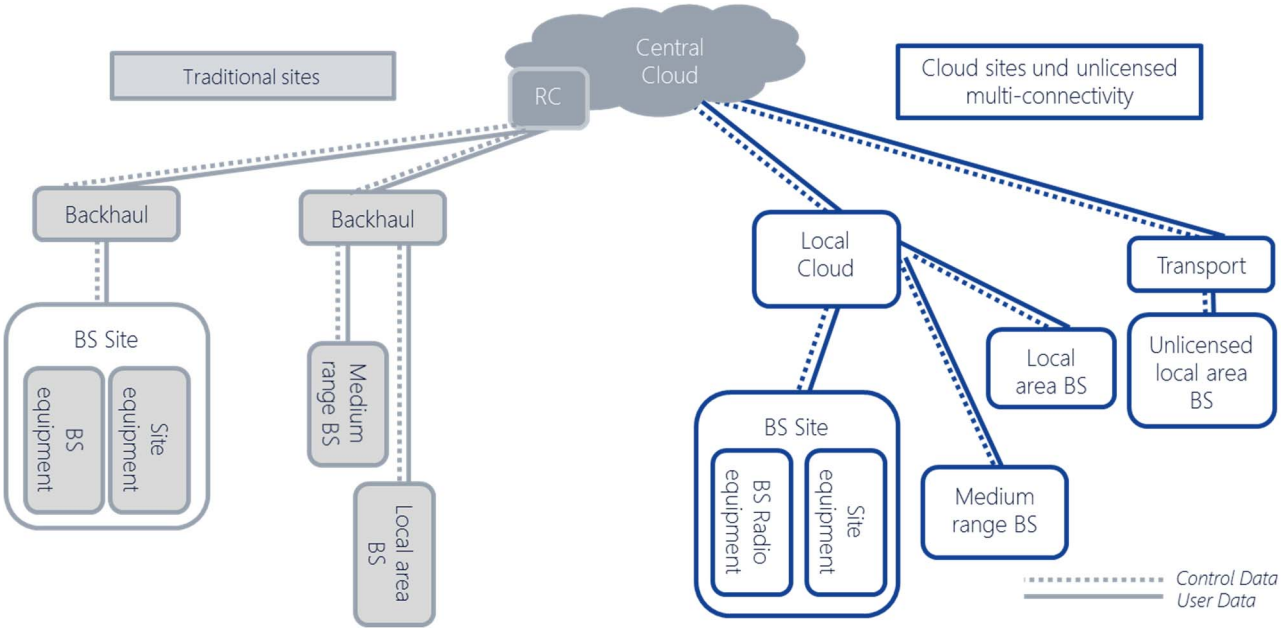

Figure 1: Network under test definition

The generic layout design for the cloud sites is defined in figure 1a.

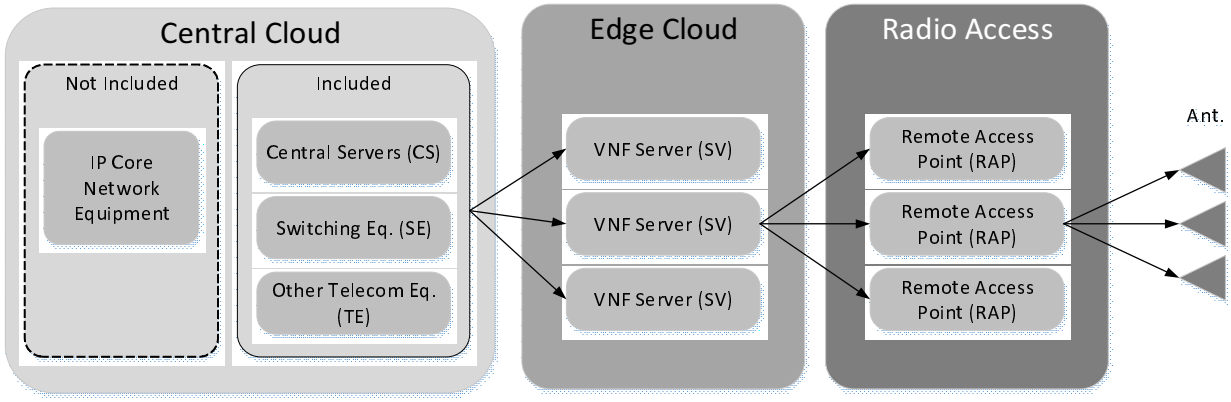

Figure 1a: Generic CRAN architecture layout

The Radio Access (RA) domain is consisting of the Remote Access Points (RAP) 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). It is installed near the transmitting antennas.

The Edge Cloud (EDC) domain is consisting of small datacentres dedicated to telecommunication functions, including Virtualised Network Functions (VNF) Servers (VNFS) used by the CRAN under investigation. A typical EDC datacentre would perform non-real time eNB tasks, such as Operations, Administration and Maintenance (O&M).

The Central Cloud (CC) domain is consisting of a multi-server Datacentre (DC) including Central Servers (CS), Switching Equipment (SE) and other Telco Equipment (TE) if needed. Central Cloud datacentres are usually very far from most of the served EDC.

4.2 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 5 (energy consumption, delivered bits, coverage) to be used to calculate the energy efficiency.

The second category includes parameters which are not directly required in the energy efficiency calculation. These parameters describe the network characteristics, such as geographical conditions, population density, coverage area, targeted data rates, climate zones, etc. and are used to interpolate from the measured sub-network to a larger network as described in clause 7. These parameters can be used to interpret variations in energy efficiency results of different networks.

Table 1: Test parameter categorization

Category	Parameter	Remarks
1	EC_{MN}	Measured network energy consumption
1	Capacity (DV)	As defined in clauses 5.2.1 and 6.2.2
1	Coverage area	As defined in clauses 5.2.2 and 6.2.3
1	Latency	As defined in clauses 5.2.3 and 6.2.4
2	Demography	Population density as defined in clause 4.3.1
2	Topography	As defined in clause 4.3.2
2	Climate zones	As defined in clause 4.3.3
2	Additional classification classes	As defined in clause 4.3.4
2	CS/PS data ratio	Describes the fraction of CS traffic vs. PS traffic in the network

4.3 Network classification

4.3.0 Introduction of network classification

To allow an extrapolation from the measured sub-networks ("partial" networks) to a complete network ("total" or "overall" networks), the test areas shall be classified into demography, topography and climate classes. These classes are described in the following clauses.

4.3.1 Demography

For the test purpose defined in the present document the mobile network shall be split into domains depending on the population density. The following population density values per domain categories shall be used, as reported in table 2.

Table 2: Sub-network 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 to 10 000
Sub-Urban (SU)	300	200 to 1 000
Rural (RU)	30	20 to 200
Unpopulated	0	< 20

Some references to data bases where the demography distribution classes are reported can be found at:

- European Eurostat Reference to demographical distribution available at:
  - https://ec.europa.eu/eurostat/web/population-demography/demography-population-stock-balance/database.
- UN Reference to demographical distribution available at:
  - https://unstats.un.org/unsd/demographic-social/index.cshtml.

- USA Reference to demographical distribution available at:
  - https://data.census.gov/cedsci/all?q=demographic&hidePreview=false&tid=ACSDP1Y2018.DP05.

4.3.2 Topography

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

Table 3: Dub-network topography classes

Topography classification		Examples
ETSI class	**Median Slope**	
1 Flat (FAO 1-3)	0 to 5 %	Denmark, Netherlands
2 Rolling (FAO 4-6)	> 5 to 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 FAO world median slope distribution information database at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ [i.5].

4.3.3 Climate zones

The following climate zones are identified, as reported in table 4.

Table 4: Sub-network 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
	Bs	Desert
C: Temperate	*Average temperature of the coldest month < 18 °C and > -3 °C, and average temperature of warmest month > 10 °C*	
	Cw	Winter dry season, at least 10 times as much precipitation in 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 (FAO Koeppen Climate Zones, Jürgen Grieser, René Gommes, Stephen Cofield and Michele Bernardi, "Data sources for FAO worldmaps of Koeppen climatologies and climatic net primary production", 2006) available at: http://www.fao.org/nr/climpag/globgrids/KC_commondata_en.asp [i.6].

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

4.3.4 Additional classification classes

In order 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, table 6 lists the classification based on data volume 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
CS	CS dominating	> 50 % of data volume is CS
PSS	PS - small packages dominating	> 50 % of data volume is PS, > 80 % of packages are small
PSL	PS - large packages dominating	> 50 % of data volume is PS, < 80 % of packages are small

5 Metrics for energy efficiency assessment

5.0 Introduction of clause

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

5.1 Energy Consumption metrics

The Mobile Network Energy Consumption (EC_{MN}) is the sum of the energy consumption of each equipment included in the MN under investigation (see clause 4). The network energy consumption is measured according to the assessment process defined in clause 6 such that individual metrics values are provided per RAT and per MNO.

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

where:

- EC is Energy Consumption.
- BS refers to the Base Stations in the MN under measurement.
- BH is the backhauling providing connection to the BSs in the MN under measurement (including transport).
- SI is the site infrastructure (Rectifier, battery losses, climate equipment, TMA, tower illumination, etc.).
- 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 6).

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 RNC share of traffic that belongs to the MN being assessed.

In order to allow a more precise assessment of the energy consumption impact of local factors (like location specific site equipment) it is recommended to report into the parameter EC_{SI_i} the measurement of the site equipment consumption into two classes:

1) ICT equipment (equipment directly needed to perform the telecommunication service).
2) Support equipment (all equipment installed at the site needed to operate the particular site but which are not directly needed for the telecommunication service, like air-conditioning, back-up power, lights, etc.).

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

Based on such a classification the following additional network metric describing the energy consumption of the telecommunication equipment with reference to the total energy consumption shall be introduced:

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

The above metric gives an indication of Site Efficiency (SEE) in terms of how big fraction of energy is used for actual telecommunication equipment (see figure 2).

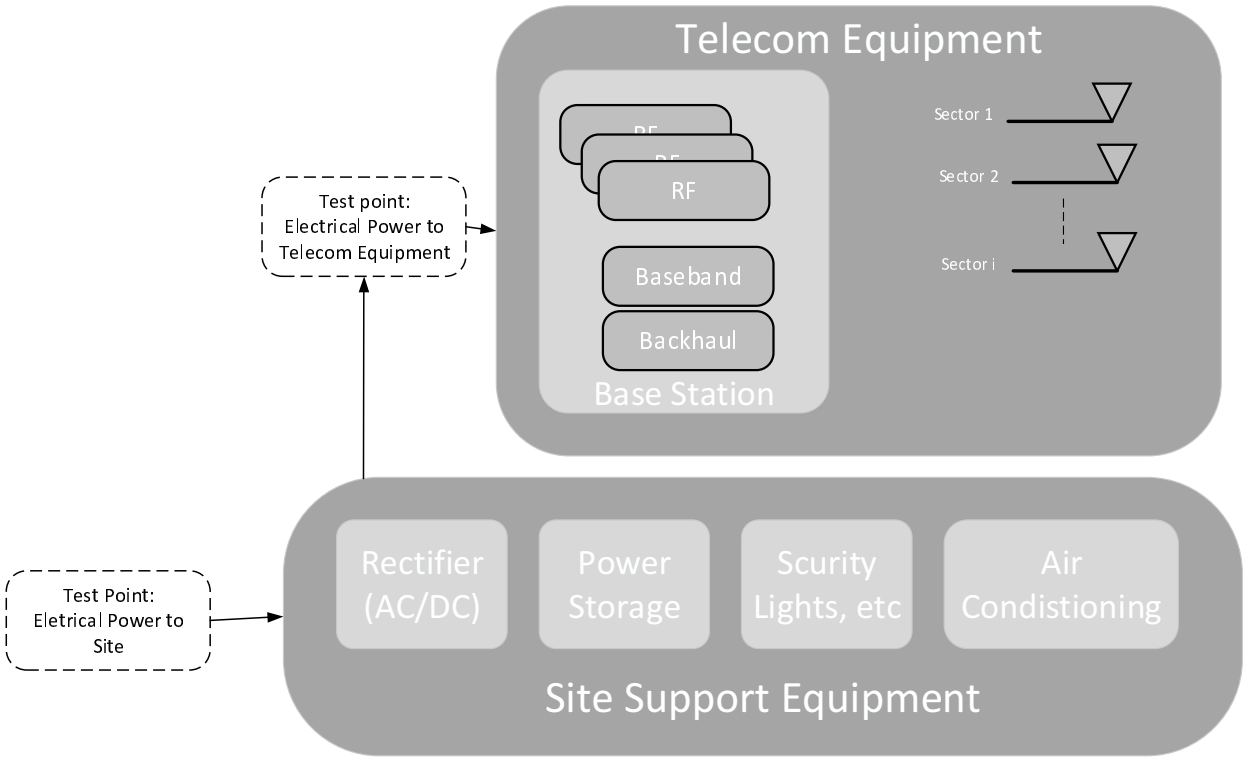

Figure 2: Layout of a typical site to determine the SEE metric

NOTE 2: Power generation is not part of MN energy efficiency, but reported for information, for use in TCO and GHG analysis.

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

The installed site equipment shall be classified in different environmental groups based on their operational temperature range (see table 7). Such a classification allows to assess 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	Temp. range	IP (Ingress Protection) code
A	0 … 28 °C	IP23
B	-20 … 40 °C	IP45
C	-40 … 55 °C	IP45

The Energy sources available in the sites (power grid, genset, etc.) shall be reported in the tables of clause 8 based on the typical layout reported in figure 3 (where the notion of "extended telecommunication site" has been included to include also the on-site electricity generation).

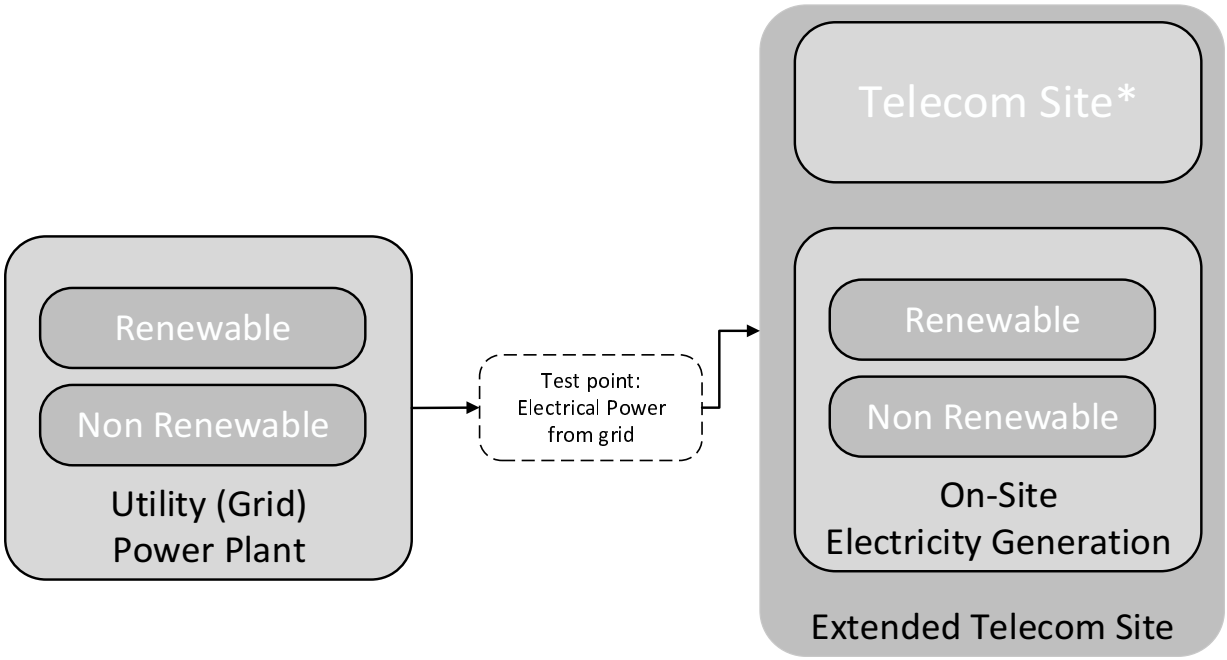

Figure 3: Schematic representation of the energy sources for a site (the * refers to the telecommunication Site as in figure 2)

The estimation of the environmental impact from the energy consumption requires additional parameters.

EXAMPLE: Greenhouse gas emissions or impact on the power grid dimensioning. Power consumption and power supply measurements/reports shall include:

- Total electrical energy consumption of the site.
- Total electrical energy consumption of the ICT equipment.
- Total electrical energy supplied from the grid.
- Peak power delivered from the grid.
- Total energy supplied in other form than electricity.
- Total amount of energy generated at the site, separated between production type (genset, solar, wind, fuel cell, etc.).
- Total site energy storage capacity.
- Peak shaving features available at the site.

The Energy Consumption of the Central and Local Cloud is measured in Wh over the period T. In case of virtualised equipment the measurement procedure for Energy efficiency is described in the ETSI EN 303 471 [11].

5.2 Performance metrics

5.2.1 Data Volume

The Mobile Network performance metrics is derived from parameters of the MN under investigation (see clause 4) 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 mobile network under investigation during the time frame T of the energy consumption assessment. The assessment process defined in clause 6 shall be used:

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

where DV, measured in bit, is the performance delivered in terms of data volume in the network over the measurement period T (see clause 6). *i* and *k* are defined in formula (1).

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

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

where DV, measured in bit, is the performance delivered in terms of data volume in the network over the measurement period T (see clause 6). *i* and *k* are like in formula (1).

Note that "circuit switched" means here all voice services, interactive services and video services managed by the MNOs, including CS voice, VoLTE and real-time video services delivered through dedicated bearers. The assessment process defined in clause 6 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 [3] and ETSI TS 132 412 [4] for LTE or equivalent used for 2G and 3G, multiplying by the measurement duration T. The counters (in ETSI TS 132 425 [3] and ETSI TS 132 412 [4]) account also for QoS being reported in QoS Class Identifier (QCI) basis (see ETSI TS 123 203 [5]).

For 5G the DV shall be derived from ETSI TS 128 552 [14] / ETSI TS 128 554 [13] in 3GPP SA5, 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 DL and UL.

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

DV_{MN} is expressed in bit.

5.2.2 Coverage Area

Coverage Area (CoA_{MN}) is also considered as a mobile network performance metric in the MN designed primarily for coverage goals (and hence especially in RU environments). The assessment process defined in clause 6 shall be used. CoA is expressed in m^2.

5.2.3 Latency

Latency is considered additionally for MN where the URLLC use cases are predominant. Latency is measured in [ms]. Within the definition of E2E latency, the User Plane latency is considered only, being more relevant in terms of application performance of the network under test. The definitions of latency are based on Recommendation ITU-R M.2410 [12].

For the measurement purposes the UP latency is:

$$T_{e2e;MN} = 2 \times (T_r + T_b + T_c + T_t) \quad (4a)$$

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 4, namely is the packet transmission time between base stations and UEs and is mainly due to physical layer communication.
- T_b is the latency introduced by the backhaul part, according to figure 4, namely is the time for building connections between base stations and the core network.
- T_c is the latency introduced by the core part, according to figure 4, namely is the processing time in the core network.
- T_t is the latency introduced by the transport part, according to figure 4, namely is the delay for the data to be sent from the core network to the Internet/Cloud.

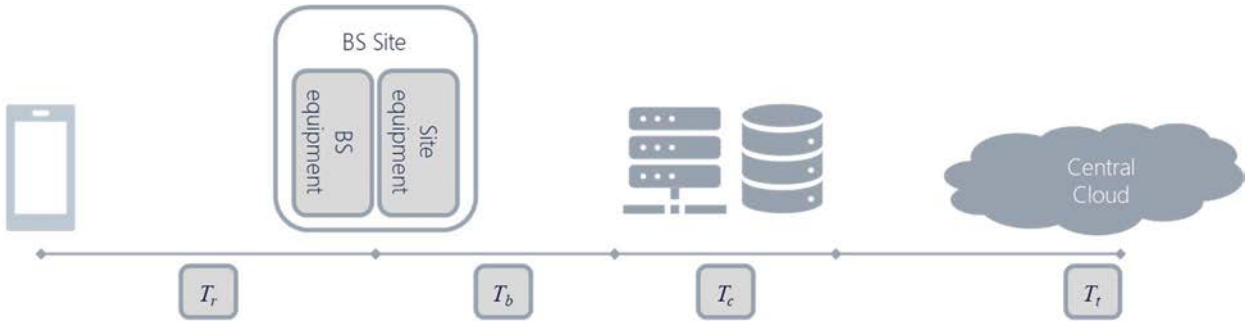

Figure 4: Definition of the end-to-end User Plane latency components

5.2.4 Massive machine type networks

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

5.3 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 frame:

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

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

Mobile Network coverage Energy Efficiency ($EE_{MN,CoA}$) is the ratio between the area covered by the MN under investigation (see clause 4) 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 6:

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

where $EE_{MN,CoA}$ is expressed in m²/J and EC_{MN} is the yearly energy consumption and $\mathrm{CoA\_des_{MN}}$ is the "coverage area" as defined in clause 6.2.3.

Latency based metric is the inverse ratio of the end-to-end User Plane latency and the energy consumed by the MN:

$$EE_{MN,L} = \frac{1}{T_{e2e,MN} * EC_{MN}} \quad (6a)$$

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

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

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

For networks with Network Slicing (NS) functionalities the EE shall be measured as follows (ETSI TS 128 554 [13]):

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

where the performance Pns is related to the type of NS implemented in the network:

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

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

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

6 Measurement of energy efficiency

6.0 Introduction of clause

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 5.

6.1 Time duration of the measurement

The time duration of the measurement, denoted as T, shall be one of the 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 is therefore one week: monthly and yearly measurements are extensions of the basic week test. For the CoA metric the Energy Consumption shall be always extrapolated to 1 year time. It is noted that T does not correspond to a granularity time or a repetition of the measurements time, that are optional values to be reported in tables of clause 8.

6.2 Measurement procedures

6.2.1 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. Moreover, sensors can be used to measure site and equipment energy consumption, following the requirements set by ETSI ES 202 336-12 [9].

The EC_{MN} is based on site granularity and includes therefore 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 case of shared infrastructure the EC_{MN} of the shared sites shall be computed per each MNO sharing those sites referring to the commercial agreements or best practises 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 in the site there are BS of different RATs the EC_{MN} shall be measured per each RAT.

The list of equipment operating in the MN sites under investigation shall be reported in the assessment report, including cooling, power conversion, etc. For a site with multi RAT equipment the energy consumption of that equipment shall be split between each RAT proportionally to the configured RF power transmitted by each RAT; further details on the multi RAT will be issued according to the development of multi RAT measurement in ETSI ES 202 706 [i.2].

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 [9]). The choice of the reporting frequency shall be documented in the assessment report.

6.2.2 Measurement of capacity

The DV_{MN} shall be measured using network counters for data volume related to the aggregated traffic in the set of BS 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 connected to the MN under test. Data volume shall be measured in an aggregated way per each RAT present in the MN.

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

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

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

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

In order to include reliability in the measurement the aggregated data volume shall be provided together with the 95^{th} 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 is out of scope of the present document.

NOTE 2: As soon as the MDT related measurements in ETSI TS 136 314 [6] 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 [6]).

6.2.3 Determination of coverage area

6.2.3.0 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 shall be described by the following parameters:

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

2) The designated coverage area (CoA_des). This area defines the area in which a network coverage is provided by the selected sub-network.

3) A coverage quality factor (CoA_Qdes). This factor takes into account measured feedback from user equipment (as described in table 8). 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.

6.2.3.1 Geographic coverage area

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

6.2.3.2 Designated coverage area

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

The designated coverage includes also in-building coverage within this area. The in-building area (for example of multi-story buildings) is only considered as the footprint of the building, not the actual building area.

6.2.3.3 Coverage quality

The actual coverage area where UEs 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 performance of the network within the actually covered fraction of the planned total coverage area. User equipment reports such as failed call attempts (table 8) shall be used to determine how well the users within the coverage area are covered.

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

A coverage map based on signal quality (SINR) like shown in figure 5 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 amount of measurements and usually drive tests.

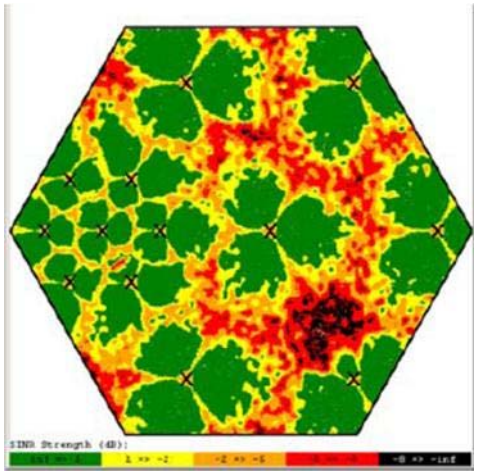

Figure 5: Typical SINR distribution of a mobile network

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

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

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

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

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

The following indicators shall be used to calculate the coverage failure (details see table 8):

1) RRC setup failure ratio (Call setup failure ratio).

2) RAB setup failure ratio (UE-BS radio interface failure).

3) RAB release failure ratio (UE-BS radio interface failure).

A further factor which can indicate a coverage issue is the handover drop ratio. However, 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 quality factor for a site is defined as follows:

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

The needed parameters are specified by 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 amount of attempts:

- RRC setup failure ratio = (Σ_k Failed RRC connection establishments$_k$)/(Σ_k Attempted RRC connection establishments$_k$).
- 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.

Table 8: Measurement parameters required for coverage quality calculation (refer to [7], [8] and [3] for 2G, 3G and 4G definition/source reference respectively)

Measurement 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*

Measurements 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 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*

Measurement 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:

$$\mathrm{CoA\_Qdes_{MN}} = \sum_i \mathrm{CoA\_Qdes_{S_i}} \mathrm{DCA_{S_i}} / \mathrm{CoA\_des_{MN}} \quad (11)$$

where:

- S refers to the sites in the MN under measurement;
- *i* is an index spanning over the number of sites.

To avoid over-counting, the '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:

$$\mathrm{CoA\_des_{MN}} = \sum_i \mathrm{DCA_{S_i}} \leq \mathrm{CoA\_geo} \quad (12)$$

where:

- S refers to the sites in the MN under measurement;
- *i* is an index spanning over the number of sites.

6.2.4 Measurement of latency

The 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: HARQ retransmission (assuming 10 % error probability).
- Step 5: Receiver processing delay in UE.

If the E2ELatency KPI, as defined in the ETSI TS 128 554 [13], clause 6.3.1.0 is available, that KPI shall be used for the metric of latency in this context.

6.2.5 Measurement of the number of subscribers

The N_{MMTC} shall be measured according to the definition reported in ETSI TS 128 554 [13], clause 6.7.2.4.1.

7 Extrapolation for overall networks

7.0 Extrapolation approach

The EE measured according to clauses 5 and 6 can be extrapolated to larger networks. When such an extrapolation is made, it shall be performed following the method presented in this clause.

The sub-network data shall be extrapolated to overall/total networks according to demography, topography and climate classifications, as described in clause 4.

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

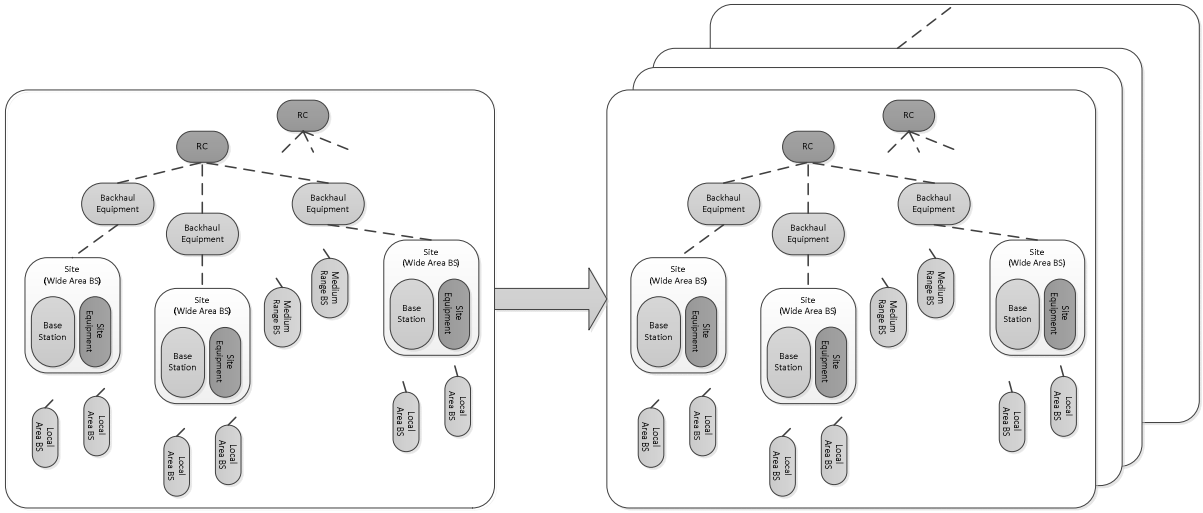

Figure 6: Extrapolation from one sub-network to a set of sub-networks ("total" network)
The layout of the partial networks should be as reported in figure 1, here simplified

7.1 Extrapolation method

7.1.0 Introduction of extrapolation method

In case the overall/total network to be addressed is not completely known in terms of demographical, topographical or climatological composition, or if the measurements of clauses 5 and 6 are executed only in some and not all the sub-networks constituting the total network, then the results shall be presented according to the tables in clause 8.

In such a case it shall be indicated for each sub-network what is its percentual recurrence 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 whole total network:

- The extrapolation procedure shall be based on the demography information classes as reported in table 2. It is optional to make extrapolation also 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 representing at least 75 % of the entire total network area demographical distribution.

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

7.1.1 Statistical information about Demography

An example of demographical information for Europe can be found in ETSI TS 132 425 [3], 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 [4]. Still another example for USA can be found in ETSI TS 123 203 [5].

7.1.2 Statistical information about Topography

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

7.1.3 Statistical information about Climate zones

An example of topography information can be found in FAO Koeppen classification [i.6], to classify the sub-network under test under a demography class as in table 4.

7.2 Extrapolation reporting tables

7.2.0 Introduction of extrapolation reporting tables

Table 9 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 the classes shall be measured, but only those classes that allow to cover 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 8 and the relative class shall be indicated. For all the same class measurement an average of EE measurements shall be reported in table 9; this shall be done both for Data Volume EE and for Coverage Area EE, whichever metric is used.

For each class then an average EE shall be computed as follows:

$$EE_{class,av} = \frac{\sum_k EE_{MN,k}}{K} \quad (13)$$

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

The Total EE shall 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 classes percentages. These percentages shall be derived from the information according to the examples of clause 7.1.

The Total EE shall be then computed as follows:

$$EE_{total} = \frac{\sum_m PofP_m EE_{class,av,m}}{\sum_m PofP_m} \quad (14)$$

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

7.2.1 Reporting extrapolation based on Demography

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

Table 9: 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)	$PofP_{U}$ [%]	$EE_{U,av}$	$EE_{U,av}$
Sub-Urban (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		$EE_{total,DV}$	$EE_{total,CoA}$

Demography table is the mandatory extrapolation representation. In case also the Topography and Climate Zone classification is available for the sub-networks measured according to clause 8 also table 10 and table 11 are to be reported.

7.2.2 Reporting extrapolation based on Topography

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

Table 10: 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		$EE_{total,DV}$	$EE_{total,CoA}$

7.2.3 Reporting extrapolation based on Climate zones

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

Table 11: 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		$EE_{total,DV}$	$EE_{total,CoA}$

8 Assessment report

8.0 Introduction of assessment report

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

The report shall include tables defined in clauses 8.1 to 8.3. 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].

8.1 Report of Network Area under test

Table 12 reports the details of the Network Area under test, representing a sub-network where the measurements are conducted. The Network Area is the area encompassing all the sites under measurement; the CoA_des_{MN} is instead computed starting from the area covered by each site (as per clause 6) and aggregating for all the sites in the Network Area under test.

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

Table 12: Report of Network Area under test

Network Area under test		
Demography class [Dense Urban, Urban, Suburban, Rural, Sparse] (table 2)		
Topography class (table 3)		
Climate zone (table 4)		
Informative classification (tables 5 and 6)		
Network Area definition [by Demography, by Geography, by Topology]		
	Number of inhabitants in the Network area *[estimate]*	
	Network Area dimensions [estimate, km²]	
	Number of sites in the Network Area [same radio controller?]	
Type of sites in the Network Area		
	Number of Wide Area BS sites	
	Number of Medium Range BS sites	
	Number of other sites/equipment (Local Area BS, 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	
	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: 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.		

8.2 Report of sites under test

Table 13: 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 IP 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 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 consumption of ICT equipment in the site [Wh]		
Energy consumption 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		

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		
Estimated percentage *of presence of this site type in the Network Area*		
Electricity sources used in the site		
	Electricity [%]	
	Genset [%]	
	Solar [%]	
	Other Renewables [%]	
	Others (indicate)	

8.3 Report of Site measurement

Table 14: Report of Site measurement

Site measurement		
Measurement duration		
	Time duration of the measurement [T]	
	Measurement start date and time	
	Measurement finish date and time	
	Repetition time	
	Granularity of measurements	
Temperature class and average temperature during the test		
Energy consumption in the site		
	Method of measurement [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 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]		
	Latency	
Number of subscribers		
	Number of subscribers	
Site Energy efficiency		
	Measured Energy Efficiency EE_{MN} [bit/J] and [m^2/J] and [ms^{-1}/J]	
	• Weekly Energy Efficiency [per week data/graph]	
	• *Monthly Energy Efficiency [if T allows]*	
	• *Yearly Energy Efficiency [if T allows]*	

9 Implementation guidelines

The present document is based on the Mobile Network Area definition under test as described in clause 4, where measurements have to be done according to the metrics as defined in clause 5 and following the procedures as defined in clause 6. In this way the network under test (composed by any radio access 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 8.

Extrapolation of sub-network results can be used for the assessment of larger networks, in particular when measurement over the whole total network is not possible due to its dimensions. In this case, the extrapolation approach defined in clause 7 shall be used.

Attention has to be paid to the selection of the sub-networks where to make the measurements, to ensure that the results are technically sound and, even if this is not the primary goal, comparable. Of course results measured in very different environments (different in terms of demography or climatology or topography, but also different due to the goal and function of the network) are hardly comparable and, as said, the purpose of the specification is not to make comparable what is not. But the important issue is to introduce a method to make tests that can represent a common reference whenever a test of mobile network energy efficiency is performed over a radio access network.

In case one network is tested against itself in different time periods a comparison could be sensible only considering with the due attention all the parameters listed in the tables of clause 8, especially referring to temperatures and environmental conditions to be aware of the possible reasons for change in the energy efficiency. Of course when considering these parameters the accuracy of the measurements has to be reported as well, in order to ensure the utmost consistency of measurements made in different 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 comparison of networks under the same constraints are sensible.

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

An essential part of this common base method is represented by the tables in clause 8. Even in very different scenarios, these tables need to be filled out completely in order for the measures to be considered as complying with the present document. In such a way even if the measurements are carried out in very different scenarios, the scenarios are described in the tables and only considering not only the final Energy Efficiency results but also how these results have been obtained the test will be considered standard compliant.

Annex A (informative): Implementation examples

A.1 Implementation examples

Considering the Implementation guidelines reported in clause 9 a set of examples on how to implement the present document is given in this clause.

A possible application of the present document 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 national, regional or city level. This assessment can be performed as a stand-alone scenario, to understand what is the efficiency reasonably achievable, or can be estimated towards a given threshold, to ensure that a minimum level of efficiency is achieved (as an example after the introduction of new energy savings procedures, or new hardware solutions).

As another example, the present document 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 different period of time, i.e. year over year or in any case so as to emphasize a time evolution of the EE performances. Of course, the full completion of the information in tables in clause 8 is mandatory to check under which conditions the tests have been performed.

As a final example, the present document could be used also without any extrapolation phase (as described in clause 7) whenever the purpose is to evaluate network functionalities that impact energy efficiency in a small network under test. In such a case the present document indicates a way 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).

A.2 Examples of reporting data

In this clause an example of data to be filled in into tables of clause 8 and clause 7 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 A.1 is table 12 filled in with example data.

Table A.1

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 (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
	Number of sites in the Network Area [same radio controller?]	30, of the same RC
Type of sites in the Network Area		
	Number of Wide Area BS sites	25
	Number of Medium Range BS sites	3
	Number of other sites/equipment (Local Area BS, relay nodes, etc.)	2

Network Area under test (Partial network #1)		
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 A.2 reports an example of a site in the Partial network #1 described in table A.1.

Table A.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	07/07/2014
	Measurement finish date and time	20/07/2014
	Repetition time	Every day
	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*		05/11/2005 initial 22/07/2013 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(s) under test in the Network Area (one table per site type to be measured in the Network Area)		
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 %
Energy consumption of ICT equipment in the site [Wh]	36 k	
Energy consumption of all the support equipment in the site [Wh]	48 k	
Energy efficiency in the site equipment (Energy_ICTequipment/Energy_Total_network)	36 / (36 + 48) = 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	84 kWh 4,7 kW 1,2 kWh 0,9 kWh	
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 A.3 reports the measurement in the site described in table A.2.

Table A.3

Site measurement		
Measurement duration		
	Time duration of the measurement [T]	2 weeks
	Measurement start date and time	07/07/2014
	Measurement finish date and time	20/07/2014
	Repetition time	Every day
	Granularity of measurements	1 min
Temperature class and average temperature during the test		
Class C, average internal temperature 24,2 °C		

Site measurement		
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 each week, according to the time granularity of the available data*
	• *Month energy consumption [if T allows]*	NA
	• *Year energy consumption [if T allows]*	NA
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 each 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 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 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 each 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 A.4 reports an example of computation results of a total Mobile Network Energy Efficiency assessment. The EE values are in the format of tables for Partial network 1, and other values are considered in other Partial networks in the same partial network area (not reported in this example) to come to the average values in the EE columns. The Total EE is evaluated in the measurement period T timeframe (2 weeks) for the DV case, while EC is extrapolated to 1 year as required for CoA EE metric.

Table A.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*
Sub-Urban (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 A.4 the following equations explain how to compute the Total EE in the cases mentioned above.

$$EE_{total,DV} = \frac{PofP_{DU} \times EE_{DU,av} + PofP_{U} \times EE_{U,av} + PofP_{SU} \times EE_{SU,av} + PofP_{Unp} \times EE_{Unp,av}}{PofP_{DU} + PofP_{U} + PofP_{SU} + PofP_{Unp}}$$

$$= \frac{42 \times 200 + 20 \times 40 + 15 \times 8 + 13 \times 2}{42 + 20 + 15 + 13} = 103{,}8\ b/J \quad \text{(A.1)}$$

$$EE_{total,CoA} = \frac{PofP_{DU} \times EE_{DU,av} + PofP_{U} \times EE_{U,av} + PofP_{SU} \times EE_{SU,av} + PofP_{Unp} \times EE_{Unp,av}}{PofP_{DU} + PofP_{U} + PofP_{SU} + PofP_{Unp}}$$

$$= \frac{42 \times 2{,}7 + 20 * 19 + 15 \times 38 + 13 \times 115}{42 + 20 + 15 + 13} = 28{,}4\ m^2/MJ \quad \text{(A.2)}$$

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).

History

Document history		
V1.1.1	April 2015	Publication
V1.1.2	January 2016	Publication
V1.2.1	April 2017	Publication
V1.3.1	October 2020	Publication
V1.4.0	February 2022	Membership Approval Procedure MV 20220403: 2022-02-02 to 2022-04-04
V1.4.1	April 2022	Publication