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Study on methods and metrics to evaluate energy efficiency for future 5G systems

ITU-T

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Summary

This Technical Paper analyses the energy efficiency issues for future 5G systems. 5G systems are the object of standardization in 3GPP and ITU and is planned to be available from 2018 in various countries. The focus of this Technical Paper is on methods and metrics to measure energy efficiency in 5G systems, with consideration of the degree of stability of the systems known so far and the experience of the legacy systems as well as related measurement procedures for evaluating future standardization evolutions.

Keywords

5G, energy efficiency, metrics, key performance indicators

Change log

This Technical Paper contains Version 1 of the ITU-T Technical Paper: *Study on methods and metrics to evaluate energy efficiency for future 5G systems* approved at the ITU-T Study Group 5 meeting held in Geneva, 15-24 May 2017.

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Study on methods and metrics to evaluate energy efficiency for future 5G systems

1 Scope

The present Technical Paper analyses the energy efficiency issues for future 5G systems. 5G systems are the object of standardization in 3GPP and ITU and are planned to be available from 2018 in various countries. The focus of this Technical Paper is on methods and metrics used to measure energy efficiency in 5G systems, with consideration of the degree of stability of the systems known to date and the experience of the legacy systems as well as related measurement procedures for evaluating future standardization evolutions.

In approach, this Technical Paper will rely on the existing standards for legacy radio systems, especially [ITU-T L.1310] for single base station measurements in a laboratory environment and [ITU-T L.1331] for access network aggregate measurements of energy efficiency. These standards are currently applied to 2G, 3G and 4G energy efficiency topics. In addition, the present Technical Paper also considers the state of the art in 5G energy efficiency studies to elaborate a first view on 5G, to be further agreed for possible future development towards a new standard of energy efficiency (EE) evaluation for 5G future systems.

2 References

[ITU-T L.1310]	Recommendation ITU-T L.1310 (2014), *Energy efficiency metrics and measurement methods for telecommunication equipment*.
[ITU-T L.1331]	Recommendation ITU-T L.1331 (2017), *Assessment of mobile network energy efficiency*.
[ETSI ES 202 706-1]	ETSI ES 202 706-1(2017), *Environmental Engineering (EE); Metrics and measurement method for energy efficiency of wireless access network equipment; Part 1: Power Consumption - Static Measurement Method*.
[ETSI ES 202 706-2]	ETSI ES 202 706-2 (Final draft) *Environmental Engineering (EE); Metrics and measurement method for energy efficiency of wireless access network equipment; Part 2: Energy Efficiency*.
[3GPP TR 38.913]	3GPP TR 38.913 (Release 14), Technical Specification Group Radio Access Network; *Study on Scenarios and Requirements for Next Generation Access Technologies*.
[3GPP TR 21.866]	3GPP TR 21.866 (Release 14), Technical Specification Group Services and System Aspects; *Study on Energy Efficiency Aspects of 3GPP Standards*.
[3GPP TR 32.856]	3GPP TR 32.856 (Release 14), Technical Specification Group and System Aspects; *Telecommunication management; Study on OAM support for assessment of energy efficiency in mobile access networks*.
[3GPP TS 32.101]	3GPP TS 32.101(Release 14), Technical Specification Group Services and System Aspects; *Telecommunication management; Principles and high level requirements*.

[3GPP TS 32.103]	3GPP TS 32.103 (Release 14), Technical Specification Group Services and System Aspects; *Telecommunication management; Integration Reference Point (IRP) overview and usage guide*.
[IMT-2020.TECH PERF REQ]	IMT-2020.TECH PERF REQ, *Minimum requirements related to technical performance for IMT-2020 radio interface(s).*
[ITU-R M.2083-0]	Recommendation ITU-R M.2083-0 (2015), IMT-Vision (M.2083) - *Framework and overall objectives of the future development of IMT for 2020 and beyond*.

3 Definitions

3.1 Terms defined elsewhere

This Technical Paper uses the following terms defined elsewhere:

3.1.1 **Virtualized Network Function (VNF):** see [b-ETSI GS NFV 003]

3.1.2 **backhaul equipment**: see [b-ITU-T L.1330]

3.1.3 **energy efficiency (EE):** see [b-ITU-T L.1330]

3.1.4 **base station (BS)**: see [b-ITU-T L.1330]

3.1.5 **distributed RBS**: see [b-ITU-T L.1330]

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

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

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

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

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

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

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

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

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

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

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

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

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

3.2 Terms defined in this Technical Paper

This Technical Paper defines the following terms:

None.

4 Abbreviations and acronyms

3GPP	3G (mobile) Partnership Project
AMF	core Access and mobility Management Function

BS	Base Station
BH	Backhaul
BHEC	BH Energy Consumption
BW	Bandwidth
CoA	Coverage Area
CS	Circuit Switched
DL	Down Link
DP	Dominant Penetration
DTX	Discontinuous Transmission
DU	Dense Urban
DV	Data Volume
EC	Energy Consumption
EDGE	Enhanced Data rate GSM Evolution
EE	Energy Efficiency
EMF	Equipment Management Function
E-UTRA	Evolved UMTS Terrestrial Radio Access Network
eMBB	extreme/enhanced Mobile Broadband
eNB	E-UTRA BS
GERAN	GSM/EDGE Radio Access Network
GSM	Global System for Mobile communication
GSMA	GSM Association
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HW	Hardware
ICT	Information Communications Technology
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MIMO	Multiple Input Multiple Output
mMTC	massive Machine Type Communications
MME	Mobility Management Entity
MN	Mobile Network

MNO	Mobile Network Operator
MP	Minor Penetration
NDP	Non Dominant Penetration
O&M	Operation & Maintenance
PDF	Probability Distribution Function
PS	Packet Switched
PSL	Packet Switched Large packages dominating
PSS	Packet Switched Small packages dominating
QoE	Quality of Experience (end-user)
QoS	Quality of Services
RAN	Radio Access Network
RAT	Radio Access Technology
RC	Remote Controller
RNC	Radio Network Controller
RRH	Remote Radio Head
RU	Rural
RX	Receiver
SCH	Signalling Channel
SINR	Signal to Interference plus Noise Ratio
SME	Session Management Entity
SU	Sub Urban
SW	Software
TCP	Transmission Control Protocol (ACK, SYN and FIN are signalling in the TCP session)
TCH	Traffic Channel
TRX	Transceiver
TX	Transmitter
U	Urban
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UN	United Nations
URLLC	Ultra-Reliable and Low Latency Communications
UTRAN	UMTS Terrestrial Radio Access Network
VNF	Virtualized Network Function

V2V	Vehicle to Vehicle
V2X	Vehicle to everything
X2	Interface allowing interconnecting eNBs with each other
WCDMA	Wideband Code Division Multiple Access

5 Introduction of 5G systems

5.1 The 5G systems

The world of mobile telecommunications experiences the introduction of a new system within a time frame of generally ten years from one system to the next. This ten year time frame can be seen in the evolution from 2G GSM systems in the 1990s to the 3G UMTS in the first decade of the twenty-first century to today's 4G long term evolution (LTE) system. Each time a new system is specified new services emerge and characterize the system: The global system for mobile communication (GSM) was considered as the standard for "voice everywhere" and the universal mobile telecommunications system (UMTS) was seen as a first introduction of "data" into a voice oriented approach while LTE is seen as a massive explosion of data traffic everywhere.

In this context, the research community had already started working on 5G systems several years ago and the first question that was raised was about the "main features" of the new system. There are three areas to which the new 5G system is dedicated: extreme/enhanced Mobile Broadband (eMBB) to further extend the data capacity and the user experienced throughput of LTE in selected environments, massive machine type communications (mMTC) to connect extremely high numbers of equipment and ultra-reliable and low latency communications (URLLC) to ensure a dramatic increase in reliability in all the connections. The usual representation of the new system is given by means of the well-known triangle of 5G services shown in Figure 1.

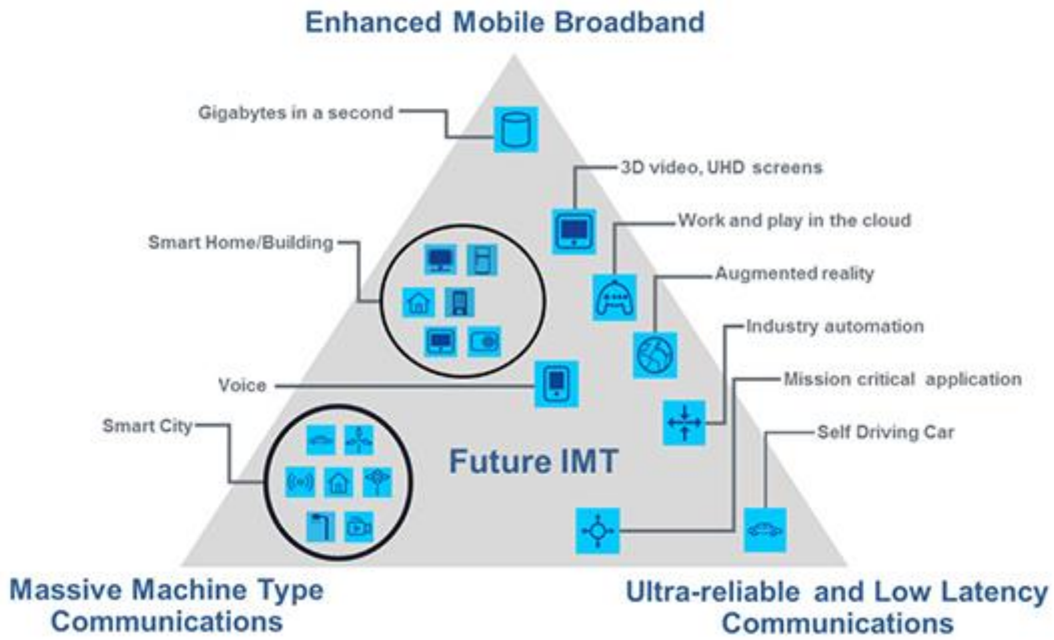

Figure 1– 5G services

- eMBB. Already today LTE offered capacity is very high, but there are some services and some applications that require even more traffic to be managed (4K videos, virtual reality, etc.) and some specific environments (offices, shopping malls, very crowded events, etc.) where the existing capacity could become an issue. To ensure the performance required by eMBB new modulation schemes and new spectrum allocations will be adopted, together with massive multiple input multiple output (MIMO), network coding and new interference management solutions.

- mMTC. Even if the so-called "Internet of Things" (IoT) is already a topic in current network deployments, the new system will bring a dramatic increase in the number of items of equipment connected and will play an essential role in ensuring the proper connection among sensors and machines. In this area the so-called "vertical" industries could play a significant role in extending the telecommunications market, especially in the automotive area (vehicle to vehicle (V2V), vehicle to everything (V2X), connected cars, etc.).
- URLLC. Previous systems did not consider reliability and safety in the transmissions as a prominent topic, but now new applications and services, such as tele-surgery, road safety and industry automation could require a huge effort in this area. This will open a significant challenge in the layout of the new system, that will have to ensure the above services and also at the same time a significant reduction in the latency of the transmission. To ensure this, the so-called "network slicing" will be probably be introduced, enabling different network implementations according to the different services and requirements.

In this context, the 5G system will then represent at the same time an evolution of the current legacy systems and a revolution to satisfy the new needs of the innovative services offered by the inclusion of new "vertical" areas in the telecommunications environment. Also in the standard this two-facet aspect of 5G is reflected in a time-wise approach, that will start with a "Release 15" new system, essentially based on an evolution of LTE, and a "Release 16" that will take care of the new vertical services and applications.

Both steps in 5G will be managed bearing in mind a set of requirements and key performance indicators (KPIs) to be satisfied (see in particular [3GPP TR 38.913] also described in clause 4.1 in this Technical Paper) and energy efficiency (EE) will be among those KPIs from the very beginning of the 5G introduction. This is because this new system by its own nature represents a challenge in terms of both offered traffic and energy consumed to provide it, as well as the complete reshaping of the traditional mobile radio access concept and layout.

5.2 The standardization roadmap of 5G

Figure 2 shows the standardization roadmap of 5G.

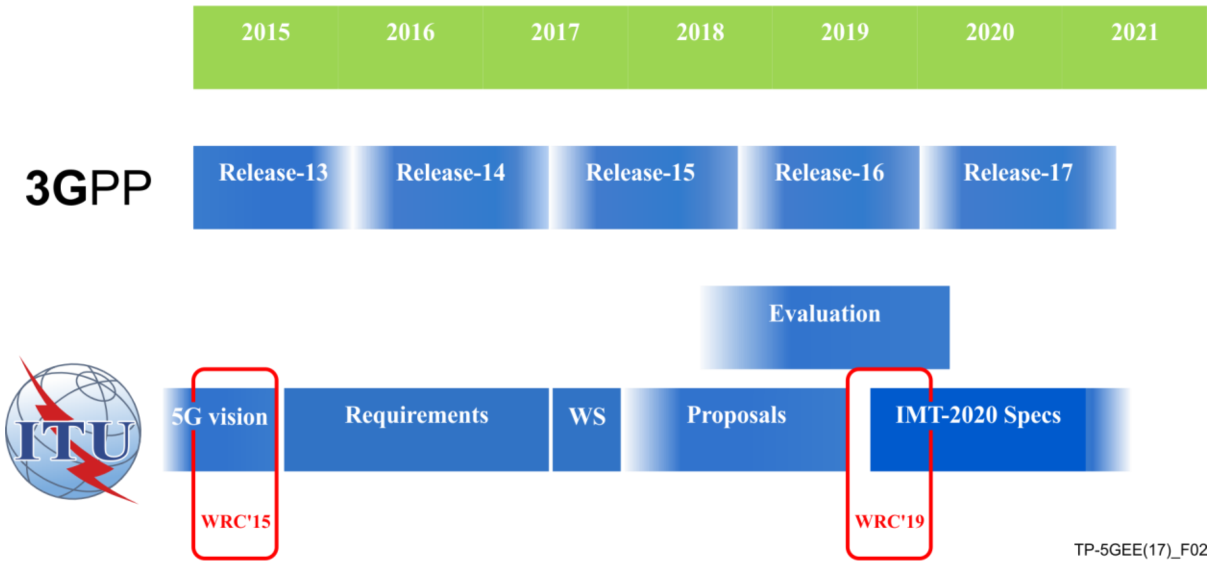

Figure 2 – The standardization roadmap of 5G

5.3 Specific aspects of 5G that impact EE

5G introduces several new services and solutions which will have a profound impact on energy consumption and energy efficiency. Key factors impacting EE:

- Higher data rates
- Lower latency
- IoT and the related low data rate services
- Carrier aggregation and multiple connectivity
- Massive MIMO
- Multilevel sleep modes
- Explicitly includes hooks to help cloudification and virtualisation
- Network slicing for different applications

Higher data rates are provided with wider bandwidth (BW) radios (at >6GHz bands). At the lower frequency, the available spectrum is limited and >20MHz continuous spectrum is rarely available for one operator. Higher data rates are thus achieved by further carrier aggregation (dual connectivity is already available in 4.5G). The need to operate multiple radio equipment or very wideband equipment for different spectrums increases energy consumption. However, carrier aggregation over a wider spectrum reduces fast fading losses and dual connectivity to multiple sites reduces interference especially at the cell border. The network energy consumption in the field (as described in [ITU-T L.1331] might be therefore lower than the sum of the equipment energy consumption measured in the laboratory (as described in [ITU-T L.1310]). This causes a significant challenge to predict actual total network energy consumption in the field based on equipment energy consumption measurements in the laboratory and assumptions or modelling of technical environment (powering solutions, back-up system, cooling, lighting, etc.) energy consumption.

5G will provide a wide range of services with different minimum latency requirements. A lower latency requirement impacts the multilevel sleep modes for base stations. This has an impact on energy consumption.

Massive MIMO and antenna beam steering solutions require many parallel transceivers (TRXs), increasing power consumption compared to current equipment because of the additional hardware overhead for the TRXs and baseband processing. On the other hand, this will improve the overall link budget, reduce interference and thereby reduce the required transmit power and improve throughput efficiency. The overall network energy efficiency gain for such configurations will need to be assessed.

Again, there will be further challenges to estimate actual network energy consumption based on equipment measurements in the laboratory. Power consumption measurements of MIMO systems are more complex because of the many possible configurations.

5G will also include more MIMO solutions in user equipment. This will increase user equipment (UE) energy consumption but can significantly degrease base station (BS) transmit power, especially for high down link (DL) data rates. The impact of UE performance has so far been neglected in the network EE discussion.

5G will also include functions that facilitate cloudification and virtualization of mobile networks. For example:

- Introduction of stateless functionalities in radio access networks (RANs) and core such as stickiness in core access and mobility management functions (AMFs).

- Itemization of functions such as the mobility management entity (MME) split into AMF and session management entity (SME), which simplifies the implementation of network slicing by enabling a greater distribution of functionalities.

Complete BS sleep modes have been implemented in many legacy networks to improve overall network EE. However, the effectiveness of these sleep modes is limited by the basic network management and control specifications of current generations. 5G will be the first cellular system were equipment sleep modes are built-in from the very beginning.

Unlike previous cellular generations, 5G will not consist of one single network technology but will comprise several inter-operational networks to provide the different services based on actual need. The energy for these networks might be not necessarily be paid from one specific operator, but could be distributed (for example through local area cellular offloading, which reduces energy consumption of the operator but increases energy consumption of the home device owner).

6 Energy efficiency metrics and methods for existing mobile systems

The Recommendation [ITU-T L.1310] is aimed at defining the topology and level of analysis to assess the energy efficiency of mobile networks, with focus on the radio access part of the mobile networks and specifically the radio base stations, backhauling systems, radio controllers and other infrastructure radio site equipment.

The covered technologies are GSM, UMTS and LTE (including LTE-A).

As a complete and detailed energy consumption measurement of the complete 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 ("sub-networks").

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

- capacity limited networks representing urban and dense urban (DU) networks;
- sub-urban networks with high requirements for coverage and capacity;
- rural networks, which are usually coverage limited.

Table 1 in clause 6.2 of [ITU-T L.1331] introduces the parameters that are relevant to evaluate and measure energy efficiency in operational networks. In particular, energy consumption (EC) is fundamental, together with "capacity" and "coverage" of the network under test.

The networks are classified on a demographic basis, i.e. taking into consideration the population density of the area under test. Five demographic classes from "dense urban" to "unpopulated" are introduced in Table 2 in clause 6.3.2 of [ITU-T L.1331]. This classification is used as a basis to make the so-called "extrapolation", i.e. the extension of the results obtained in a small area where the measurements are made up to a bigger network (corresponding to a whole region, a whole country, or the whole network managed by an operator).

Other classification criteria of small networks are given, and they are reported in the measurement reports (defined in clause10 of [ITU-T L.1331]).

The overall EC of the partial network under test is measured as follows:

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

where

- EC is energy consumption.
- BS refers to the base stations in the mobile network (MN) under measurement.

- BH is the backhauling providing connection to the BSs in the MN under measurement.
- 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.
- *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.

The capacity is measured in terms of data volume (DV), including both circuit switched and packet switched DV according to the mobile system. The coverage is estimated according to network operators' planning strategies.

The overall energy efficiency is given in two forms, based either on capacity as defined in clause 7.1 of [ITU-T L.1331]:

$$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}} \qquad (2)$$

or on coverage as defined in clause 8.3.3 of [ITU-T L.1331]:

$$EE_{MN,CoA} = \frac{\text{CoA\_des}_{MN}}{EC_{MN}} \qquad (3)$$

Clause 8.2 of [ITU-T L.1331] illustrates how to measure/collect the information about data volume (for capacity), coverage area (for coverage) as well as energy consumption over a measurement period called T, that can span over one week, one month, or longer periods.

It is worth noting that both for coverage and for capacity the measured values are given with an indication of the "quality" perceived by the users, related to the concept of "useful" energy consumption only and in order not to consider the wastage of energy due to un-requested services or services related only to network management.

Finally, and as already stated, [ITU-T L.1331] describes how to extend the application of the results obtained by measuring a small area to wider networks. This is based essentially on the extrapolation process from the demographical data of the areas under test, used as a reference for similar areas in bigger networks. A threshold (75%) is given to be able to safely express the energy efficiency of a wide area, i.e. that area shall be based on a demography that can be measured in the different topologies with a level of representation of at least 75% of the whole extrapolated area.

6.1 Introduction of work on energy management in STF516

ETSI is currently in the process of defining a series of ENs related to energy management of information and communication technology (ICT) systems and equipment within STF516 providing energy efficiency KPI’s and assessment principles. These standards are still under development and might be applicable as EN when 5G will be deployed. Therefore, it is recommended to take them into consideration, including standards dealing with fixed networks that may impact 5G cloudification.

This includes the documents listed in Table 1:

Table 1: STF516 deliverables

STF WI	STF name	Title
D1	EN 305 174-2	Broadband Deployment and Lifecycle Resource Management; ICT Sites Lifecycle Resource Management; ICT Sites
D2	EN 305 200-1	Energy management; Global KPIs; Operational infrastructures Part 1: General requirements
D3	EN 305 200-2-1	Energy management; Operational infrastructures; Global KPIs; Part 2: Specific requirements Sub-part 1: ICT sites
D4	EN 305 200-3	Energy management; Global KPIs; Operational infrastructures; Specific requirements; Global KPI for ICT Sites
D5	EN 303 470	Measurement Process for Energy Efficiency KPI for Servers
D6	EN 305 200-2-2	Energy management; Global KPIs; Operational infrastructures; Specific requirements; Fixed Broadband access networks
D7	EN 305 200-2-4	Energy management; Global KPIs; Operational infrastructures; Specific requirements; Cable access networks
D8	EN 305 200-2-3	Energy management; Operational infrastructures; Global KPIs; Part 2: Specific requirements Sub-part 3: Mobile broadband access networks
D9	EN 303 472	Measurement Process for Energy Efficiency KPI for RAN Equipment
D10	EN 305 174-5-1	Broadband Deployment and Lifecycle Resource Management; Lifecycle Resource Management; Customer network infrastructures; Homes (single-tenant) Customer network infrastructures; Homes (single-tenant)
D11	EN 305 174-1	Broadband Deployment and Lifecycle Resource Management Part 1: Overview, common and generic aspects
D12	EN 303 471	Energy efficiency measurement method and KPIs of Network Function Virtualization (NFV) applications in ICT networks
D13	EN 305 174-8	Broadband Deployment and Lifecycle Resource Management; Management of end of life of ICT equipment (ICT waste / end of life)

Deliverables D5 (EN 303 470), D12 (EN 303 471) and D9 (EN 303 472) provide measurement methods and KPIs like the previously mentioned [ITU-T L.1310] and [ITU-T L.1331].

EN 303 472 fills the gap between [ITU-T L.1310] (BS laboratory efficiency) and [ITU-T L.1331] (network efficiency) with a detailed site measurement method.

EN 303 471 shall provide methods to measure the impact of EE from virtualization in networks.

EN 303 470 provides methods to measure EE of servers.

The deliverables D2, D3, D4, D6, D7 and D8 (EN 305 200-series) deal with energy management with respect to the usage of renewable energy and potential reuse of heat from ICT equipment.

Deliverables D1, D10, D11 and D13 (EN 305 174-series) deal with end-of-life management of ICT equipment. Despite the current name of the EN 305 174-series (Lifecyle management) this document does not cover life cycle management in accordance to generally accepted life cycle assessment (LCA) methods (for example [b-ITU-T L.1410], etc.).

7 State of the art approaches

7.1 3GPP RAN

In 3GPP RAN the TR [3GPP TR 38.913] is under preparation.

The TR [3GPP TR 38.913] is titled *Study on Scenarios and Requirements for Next Generation Access Technologies (Release 14)* and is developed by the Technical Specification Group on Radio Access Network.

In the Scope, it is stated that the TR "contains scenarios and requirements for next generation access technologies, which can be used as not only guidance to the technical work to be performed in 3GPP RAN WGs, but also input for ITU-R to take into account when developing IMT-2020 technical performance requirements."

A first part of the TR is dedicated to a summary of the possible 5G scenarios.

In a second part the TR deals with the KPIs to be used to evaluate the performance of the new network in these scenarios. Among these KPIs, in section 7 of the 3GPP RAN TR, one paragraph is dedicated to "UE energy efficiency" (7.12), another to "Area traffic capacity" and the "User experienced data rate" (7.14). These two latter KPIs are relevant for the energy efficiency estimation.

Finally, section 7.19 is dedicated to "Network energy efficiency". In this section, it is clearly stated that "Network energy efficiency shall be considered as a basic principle in the NR design", where NR is the acronym for the new 5G set of systems. Qualitative inspection is suggested, for energy efficiency, but also quantitative analysis, in particular for:

- comparing different solutions or mechanisms directly related to energy efficiency, when their impact is not obvious from qualitative analysis
- comparing the final NR system design with LTE to evaluate the overall improvement brought in terms of network EE

The suggested quantitative KPI is:

$$EE_{global} = \sum_{scenario\ K} b_K EE_{scenario\ K}$$

where

$$EE_{Scenario} = \sum_{load\ level\ 1} a_1 \frac{V_1}{EC_1}$$

"b" spans over the deployment scenarios, and "a" over the load levels in each scenario. "V" is the traffic per second served by a base station and "EC" is the power consumed by a base station to serve V.

The suggested KPIs in this 3GPP RAN TR are for special use in simulations. They should be evaluated by means of system level simulations at least in two deployment scenarios: one coverage limited environment (ex: Rural) AND one capacity limited environment (ex: Urban). At least 3 load levels should be evaluated.

7.2 3GPP SA

In 3GPP SA the TR [3GPP TR 21.866] is under preparation.

The TR [3GPP TR 21.866] is titled *Study on Energy Efficiency Aspects of 3GPP Standards (Release 14)* and is developed by the Technical Specification Group on Services and System Aspects.

Firstly, the report deals with the so-called "3GPP system energy efficiency requirements and principles" and identifies four of them:

- High level requirements, where the landscape for energy efficiency in mobile radio systems is set up
- Architectural requirements, where the architectural approaches to save energy are mentioned
- Functional requirements, where the possible impacts of energy efficiency on network performance is dealt with
- The energy efficiency control principles, where a list of possible actions to increase energy efficiency is given.

Secondly, the TR presents a section on the key issues related to energy efficiency. In this section there is a paragraph referring to energy efficiency KPI definitions and it is the paragraph that could be considered the most relevant for the purposes of the present TR. In particular, in section 5.1.2, the 3GPP TR indicates the EE definition as:

$$EE_{scenario\ i} = \sum_{load\ level\ l} a_l \frac{V_l}{EC_l}$$

where the concept of "scenario" is introduced to identify a specific network environment where EE is measured. In particular, V is the aggregated throughput and EC the consumed energy to give such a throughput. The overall EE is summed up over all the scenarios as:

$$EE_{global} = \sum_{scenario\ i} b_i EE_{scenario}$$

In this approach two "weights" (a and b) are introduced, to consider the different load levels and the different scenarios to evaluate the overall EE. As a complement, the 3GPP TR considers also the coverage metric developed in [ITU-T L.1331]:

$$EE_{global,\ CoA} = \sum_{scenario\ i} C_i \frac{coverage\ area_i}{EC_i}$$

with a third weight "c" to consider possible different coverage scenarios in different ways. A first rough indication on how to evaluate weights b and c is given in section 5.1.3.3, while for the "network loads", related to the definition of weight a, the section 5.1.4 gives some further information.

For the deployment scenarios a table is provided in section 5.1.3, with a clear reference to possible 5G scenarios (see Table 5.1.3.2-1).

In the current last section, the 3GPP TR deals with the possible solutions to improve energy efficiency and these are in any case outside of the scope of the present TR.

7.3 Other references

In the ITU-R Recommendation dated September 2015, known as the ITU-R Vision Recommendation [ITU-R M.2083-0], in clause 2.3.6 it is stated: "In order to enhance energy efficiency, energy consumption should be considered in the protocol design. The energy efficiency of a network can be improved by both reducing RF transmit power and saving circuit power. To enhance energy efficiency, the traffic variation characteristic of different users should be well exploited for adaptive resource management. Examples include discontinuous transmission (DTX), base station and antenna muting, and traffic balancing among multiple RATs." Moreover, in clause 3.2 one of the "roles" of ITU is foreseen to be to "Promote Energy Efficiency: IMT enables energy efficiency across a range of sectors of the economy by supporting machine to machine communication and solutions such as smart grid, teleconferencing, smart logistics and transportation." Finally, in the general "capabilities" that an IMT system shall have, ITU recognizes that "Energy efficiency has two aspects: – on the network side, energy efficiency refers to the quantity of information bits transmitted to/ received from users, per unit of energy consumption of the radio access network (RAN) (in bit/Joule); – on the device side, energy efficiency refers to quantity of information bits per unit of energy consumption of the communication module (in bit/Joule)." The energy consumption for the radio access network of IMT-2020 should not be greater than IMT networks deployed today, while delivering the enhanced capabilities. The network energy efficiency should therefore be improved by a factor at least as great as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for enhanced Mobile Broadband".

Next Generation Mobile Networks (NGMN) published a White Paper in 2015 that was considered as a basis for the development of 5G systems. In the White Paper, NGMN states that "Business orientation and economic incentives with foundational shift in cost, energy and operational efficiency should make 5G feasible and sustainable. "In particular, section 4.6.2 is thoroughly dedicated to energy efficiency, and it is stated that "Energy efficiency of the networks is a key factor to minimize the TCO, along with the environmental footprint of networks. As such, it is a central design principle of 5G." "Energy efficiency is defined as the number of bits that can be transmitted per Joule of energy, where the energy is computed over the whole network, including potentially legacy cellular technologies, radio access and core networks, and data centres. 5G should support a 1 000 times traffic increase in the next 10 years timeframe, with an energy consumption by the whole network of only half that typically consumed by today's networks. This leads to the requirement of an energy efficiency increase of x2000 in the next 10 years timeframe. Every effort should be made to obtain the energy gain without degrading the performance, but the technology should allow native flexibility for the operator to configure trade-off between energy efficiency versus performance where justified."

5GPPP (5G Public-Private Partnership) published a White Paper in April 2016 dedicated to "5GPPP use cases and performance evaluation modelling." In this White Paper there are some references to energy efficiency. Related to MTC "mMTC device energy consumption improvement is defined as the relative enhancement of energy consumption of 5G devices over LTE-A ones, under the assumption that device is stationary and uploads a 125 byte message every second. If not mentioned explicitly, energy consumption in RRC idle state is assumed the same for LTE-A and 5G devices." More generally, on RAN efficiency "Energy efficient network operation is one of the key design objectives for 5G. It is defined as the overall energy consumption of 5G infrastructure in the RAN comparing to a performance of legacy infrastructure. In order to prove expected energy savings both spatial (entire network) and temporal (24 hours) variations need to be taken into account, therefore direct evaluation in proposed Use Cases is inaccurate." (This is actually the same as in METIS-II deliverable D2.1, see below).

METIS-II (Mobile and wireless communications Enablers for the Twenty-twenty Information Society-II) deliverable D2.1 ("Performance evaluation framework"). In the section about KPIs definition the following is reported: "Energy efficient network operation is one of the key design objectives for 5G. It is defined as the overall energy consumption of 5G infrastructure in the RAN comparing to a performance of legacy infrastructure. In order to prove expected energy savings both spatial (entire network) and temporal (24 hours) variations need to be taken into account, therefore direct evaluation in proposed Use Cases is inaccurate." Moreover (in section 2.5): "as a general requirement, network energy efficiency (Joules per bit) must be increased by a factor of 100 as compared with LTE-A in current deployments whereas energy consumption for the RAN of IMT-2020 should not be greater than networks deployed today ITU-R 15-M2083." Finally section 4.6.3 reports a possible "power model" of the radio nodes, to be taken into consideration especially in simulations.

- METIS-II published another deliverable D2.3 ("Performance evaluation results") where the findings of D2.1 are further elaborated. In particular there is the Annex A of this deliverable dealing with a new method to simulate the network energy efficiency. This method is based on the following steps:
    - Step 1. Calculate traffic volume density for a 5G dense urban deployment according to procedure defined in MII16-D21 (METIS-II deliverable D2.1), and estimate corresponding packet inter-arrival time (IAT)
    - Step 2. Scale obtained IAT to calculate different load levels for 5G.
    - Step 3. Repeat Step 1 and 2 to calculate IAT for rural 5G network deployments taking into account different experienced user throughput KPIs.
    - Step 4. Use calculated IATs/load points to obtain the total radio network power consumption at given load via simulations.
    - Step 5. Redo Steps 1-4 for baseline 4G.
    - Step 6. Integrate results obtained with above-mentioned setups with different weights to calculate overall energy efficiency improvements of the network.

  Note that for the Step 6 above METIS-II suggest the usage of the formulas from 3GPP RAN TR38.913.
- ITU-R [IMT-2020.TECH PERF REQ]. This Report describes key requirements related to the minimum technical performance of IMT-2020 candidate radio interface technologies. It also provides background information about individual requirements, including energy efficiency. It is required that the 5G mobile networks have the capability to support a high sleep ratio and long sleep duration and other energy saving mechanisms for both networks and devices are encouraged.

8 Proposed metrics for 5G energy efficiency

8.1 Metrics for 5G "first phase" (Release 15)

The first phase of 5G will start earlier and will be based quite likely on the eMBB services only.

In this sense, the first phase will be quite an evolution of the legacy 2G, 3G, 4G networks, with an architecture similar to those already in place. Differences could be limited to the wider adoption of virtualization and orchestration in the core network and to a wider usage of small cells to have the required network densification. It could also happen that new frequency bands will be adopted, more likely in the above 6 GHz spectrum and for front-back/hauling purposes more than for the access.

Consequently, the network that will be called "5G" will be possibly analysed in terms of energy consumption and energy efficiency aspects in the same way, or very similarly, to what is already specified for 2G, 3G and 4G networks in [ITU-T L.1331]. The single nodes will be measured referring to [ETSI ES 202 706-1] and [ETSI ES 202 706-2] for both static and dynamic operations.

Indeed, the capacity and coverage definitions, as given in [ITU-T L.1310] and [ITU-T L.1331] and summarized in clause 6 of this TP, still hold for this phase of 5G, as well as, even more, for the energy consumption measurement.

A challenge arises from the increasing use of multi-radio equipment. Specific 5G base stations will be installed for dense urban high capacity sites. In most other cases, 5G will be collocated at existing sites. Most of today's new base stations can be configured to operate with different technologies (GSM, HSPA and LTE) simultaneously and even multi-band base stations are now available. Consequently, many new 5G BS will be multi-standard capable. There currently exists no unambiguous method to measure the fraction of energy consumed by a multi-standard BS for the different standards.

In [ITU-T L.1310] every BS (also multi-standard BS) is measured separately for each technology with the load levels defined in the standard. The testing for simultaneous use of two technologies is defined in detail in [ETSI ES 202 706-1] and [ETSI ES 202 706-2]. However, the resulting power and energy measurements provide the total equipment power consumption only. [ETSI ES 202 706-1] and [ETSI ES 202 706-2] should also address the energy consumption of large antenna array systems taking into account traffic profiles and beam forming functionalities.

The efficiency KPIs in [ITU-T L.1331] can be only applied per technology, if separate equipment is used. In the case of multi-standard equipment, the measured KPI provides the average site efficiency measured over all equipment.

The approaches described in clause 6 from 3GPP (especially sub-clauses 6.1 and 6.2) are to be used only for simulations purposes. The introduction of the weights therein (a, b and c) are not supported for any real measurement approach, since the weights introduce a level of arbitrariness which disguises the real measurement results and leave the resulting KPI meaningless.

More specifically, the weight factor "a_i" that spans over the load levels and is present in 3GPP formulas in clauses 6.1 and 6.2, is used in laboratory tests (see [ITU-T L.1310]) and is not needed in field measurements since the network is not artificially loaded but is in its operational state. The different load levels are taken into consideration extending the measurement for a period T, as prescribed in [ITU-T L.1331] and T is long enough to include all possible network states in terms of load.

Related to the weight factor "b_i", it spans over the different "scenarios". This is a typical parameter used in simulations. In the measurements, the approach that performs best is the one based on extrapolation, as described in [ITU-T L.1331]. With such an approach the parameters b_i has no value, since it is implicitly introduced considering the percentage of presence of the measured small network with respect to the overall network to be extrapolated. A weighting of the different sub-networks with a specific multiplicator will hide inherent efficiency problems of certain network deployments, as the inefficient areas are "corrected" with a weight factor instead of alternative more efficient solutions.

Finally, referring to the parameters "c_i", currently adopted only in the 3GPP SA TR 21.866, they consider the different "coverage scenarios". In clause 8.3.3 of [ITU-T L.1331] there are already very precise methods to consider the coverage areas under test. Also for coverage based metrics the extrapolation method holds, still based on the demographic context of the small areas that are measured. In this way, also the parameters "c_i" are not supported and the usual extrapolation approach is still deemed as valid. As with the weight factor "b_i", the proposed "c_i" will only hide efficiency problems but does not contribute to a conclusive network assessment.

To conclude and summarize, the metrics and methods described in [ITU-T L.1331]for the legacy networks are considered valid for 5G Phase 1 and an update of the [ITU-T L.1331]will be issued once the 5G Phase 1 details will be standardized.

8.2 Metrics for 5G "future phases" (Release 16 and beyond)

The second phase of 5G will probably coincide with the Release 16 and onwards in 3GPP and is then expected not earlier than 2019-2020 according to the different countries decisions. This second phase will be quite likely based on an evolution of the "Internet of Things" encompassing sensors, devices, vehicles and brand new network layouts.

This network will probably leverage the most on the so-called "network slicing" concept and each "slice" of the network will have a different architecture in terms of access and core parts. Every slice will be quite likely a new "network" for the sake of energy consumption and efficiency, being made of different real and virtual components.

One possible approach could then be to introduce a different measurement method for each slice in the network.

The approach in [ITU-T L.1331] could then still work, but new network elements could be introduced in the formulas to evaluate the energy consumption, according to the network layout of every single slice. Probably also the measurements of the capacity should be accorded to the single slice under test and its typical throughput values. The same for the coverage, that of course will be very different if sensors/actuators or vehicles or other network elements will be analysed.

Also the [ITU-T L.1310] and the standards [ETSI ES 202 706-1] and [ETSI ES 202 706-2] will have to be extended to the new network elements in 5G Phase 2. In particular, it shall no longer be based only on the measurements of radio base stations as intended today, but it shall also include methods and measurements descriptions for the impact of the performance of devices, sensors, actuators and vehicles, as a first set that can be imagined already today.

To conclude and summarize, the Phase 2 of 5G, that will come in 3-4 years from today, will impact heavily the specifications to measure energy efficiency and will require an extensive update of them, in tight cooperation with the standard bodies that will outline the new systems, especially 3GPP RAN and ITU-R. The objective is for example to leverage 3GPP SA5 work dealing with energy efficiency related analytics.

9 Future work

While 5G standardization is still progressing, it is proposed to develop a step by step approach that is addressing the already existing functionalities. The objective is to be able to test and benchmark the energy consumption and energy efficiency improvements of functionalities under development or under standardization.

As a first step, the following is proposed:

- New WI to cover the following topics:
  - antenna array systems used in mMIMO (in particular the definition of traffic models, the impact of number of beams and beam steering, etc.)
  - improve specification of base band consumption testing including base band hostel use case

    - advanced sleep modes (informative annex)
- New WI to complement [ITU-T L.1331] with the following topics
    - multi-techno networks (hetnet)

As a second step, the following is proposed:

- New WI to cover following topics
    - advanced sleep modes
- New WI to complement [ITU-T L.1331] with the following topics:
    - develop energy KPIs/counters and energy efficiency analytics (liaison with SA5)
    - Cloud RAN

Bibliography

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

[b-ITU-T L.1410] RecommendationITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

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

[b-ETSI GS NFV 003] ETSI GS NFV 003 V1.2.1 (2014), *Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV.*