



TECHNICAL REPORT

Environmental Engineering (EE); Study of multi-dimensional network energy efficiency metrics

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Foreword

This Technical Report (TR) 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 and published respectively by ITU and ETSI as Supplement ITU-T L.Suppl. 62 [i.6] and ETSI Technical Report ETSI TR 104 084 (the present document), which are technically equivalent.

Modal verbs terminology

In the present document **"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).

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Executive summary

Existing network energy efficiency metrics are typically only based on the amount of service provided, e.g. transported data volume, coverage area, or number of connections. Other dimensions of useful work, e.g. the quality of the service provided, is seldom reflected, and it is also not always clear if/how these metrics can be combined to give a more complete picture of the energy efficiency of a network. The scope of the present document is to study existing network energy efficiency metrics and outline proposals on how network energy efficiency metrics capturing multiple performance dimensions (service volume, service quality, service availability, etc.) can be formulated. These can be combinations of existing network energy efficiency metrics, but also new proposals capturing performance dimensions not considered today. The focus has been on network energy efficiency metrics to be used for monitoring and/or optimization of live networks, even though metrics for reporting and related implications have been also covered.

The analysis concludes that it is desirable that in addition to the existing mostly service-volume based EE metrics, also service quality is added into the EE assessment. In particular, service quality based on (average) user throughput may be valuable to consider in addition to data volume when assessing mobile network data energy efficiency, something that has also been concluded by 3GPP. It is also desirable to extend the current mobile network coverage energy efficiency analysis to consider differences in coverage quality in addition to coverage availability. Whether also service availability should be considered is less obvious, as the analysis conducted shows limited value to add such metrics into the assessment.

Three multi-dimensional metric proposals, i.e. structures for considering multiple performance dimensions in the EE assessment, have been defined and assessed in the present document:

- **Metric based on adjustment factor(s):** A base metric, typically the existing service volume-based EE metrics already defined, is extended (i.e. multiplied) by a dimension-less adjustment factor. The idea is that the adjustment factor captures another performance dimension and scales the base metric accordingly.
- **Multiplicative metric:** In this case, two performance indicators are multiplied and considered in relation to the network energy consumption.
- **Separate metrics per performance dimension:** Multiple single-dimensional energy efficiency metrics represent the different performance dimensions in the network energy efficiency evaluation.

Of these, the second proposal - multiplicative metric - has been assessed as least attractive. It can be difficult to understand, as it mixes units of different performance metrics and relates them to the energy consumption at the same time. It may then be difficult to understand how the metric behaves, and what it really tells. The other two have their pros and cons depending on the use case. Using separate metrics per performance dimension is beneficial for a more nuanced assessment, as it reveals all details of what is driving the results. However, it may make an optimization algorithm more complex with more variables to consider. A metric based on adjustment factors may hide nuances, but with just one or two performance indicators reflected this risk is reduced. Furthermore, if it is constructed in a sound way it should be easy to understand, e.g. with service volume scaled by a factor based on service quality. It may in particular be useful for network optimization.

For reporting, it is recommended to keep the existing single dimensional metrics, e.g. mobile network data energy efficiency, as they have been used for long time, are well-known, and also requested in some reporting frameworks.

Furthermore, the analysis also confirms that contextual factors such as geographical conditions, population density, topology, climate zones, and also regulatory obligations on coverage and service quality, may have a significant impact on the energy efficiency assessment and its' results. Therefore, this again emphasizes that the network level energy efficiency analysis and metrics should not be used for benchmarking of different networks (unless the contextual factors are the same or compensated for), rather the use case is for assessing improvements over time in a specific network and optimization of the network.

Introduction

A mobile network needs to fulfil several service requirements, such as being able to deliver a certain service volume with a given service quality and service availability. A number of different energy efficiency metrics have been defined throughout the years, e.g. for mobile networks in ETSI ES 203 228 [i.1]. These metrics are typically used to assess the energy efficiency of the network over time, but can also be used in network optimization algorithms for improving the network energy efficiency in an automated manner. The metrics should not be used for benchmarking of different networks, as contextual factors of different networks such as regulatory obligations, emergency service requirements, geographical and population characteristics, etc. significantly influence the metrics.

These existing network energy efficiency metrics are typically only based on the amount of service provided, e.g. transported data volume, coverage area, or number of connections. However, the quality of the service provided is seldom reflected, and it is also not always clear if/how these metrics can be combined to give a more complete picture of the energy efficiency of a network.

The present document studies existing network energy efficiency metrics and outlines proposals and analysis on how mobile network energy efficiency metrics capturing multiple performance dimensions (service volume, service quality, service availability, etc.) can be formulated.

1 Scope

The present document studies existing network energy efficiency metrics and outlines proposals how network energy efficiency metrics capturing multiple performance dimensions (service volume, service quality, service availability, etc.) could be formulated. These can be combinations of existing energy efficiency metrics, but also new proposals capturing performance dimensions not considered today. The focus is on network energy efficiency metrics to be used for monitoring and/or optimization of live networks.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

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.

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The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

- [i.1] ETSI ES 203 228 (V1.4.1): "Environmental Engineering (EE); Assessment of mobile network energy efficiency".
- [i.2] ETSI TS 128 554 (V19.5.0): "5G; Management and orchestration; 5G end to end Key Performance Indicators (KPI) (3GPP TS 28.554 version 19.5.0 Release 19)".
- [i.3] ETSI TR 128 913 (V18.0.1), "5G; Study on new aspects of Energy Efficiency (EE) for 5G phase 2 (3GPP TR 28.913 version 18.0.1 Release 18)".
- [i.4] ETSI TS 132 450 (V18.0.0): "Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Key Performance Indicators (KPI) for Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Definitions (3GPP TS 32.450 version 18.0.0 Release 18)".
- [i.5] 3GPP TR 28.880 (V19.0.0 - 2024-12): "Study on energy efficiency and energy saving aspects of 5G networks and services (Release 19)".
- [i.6] ITU-T L.Suppl. 62: "Study of Multi-dimensional network energy efficiency metrics".
- [i.7] Recommendation ITU-T L.1015 (05/19): "Criteria for evaluation of the environmental impact of mobile phones".
- [i.8] Recommendation ITU-T K.114 (08/22): "Electromagnetic compatibility requirements and measurement methods for digital cellular mobile communication base station equipment".
- [i.9] Recommendation ITU-T E.805 (12/19): "Strategies to establish quality regulatory frameworks".
- [i.10] ETSI ES 202 336-12 (V1.3.1): "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".
- [i.11] JRC144975 (2026) Baldini, G. Cerutti I: "EU Code of Conduct for the sustainability of telecommunications networks".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

end-to-end latency: time taken 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

NOTE: As defined in [i.1].

energy efficiency: relation between the useful output and energy/power consumption

NOTE: As defined in [i.1].

multi-dimensional network energy efficiency: network energy efficiency assessment or metric based on multiple performance indicators from different performance dimensions

reliability: probability that a product functions as required under given conditions, including maintenance, for a given duration without failure

NOTE: As defined in [i.7].

service availability: availability of the service provided by the network, for example in time or space

service quality: quality of the telecommunication services provided by an operator

NOTE: As defined in [i.9].

service volume: volume of the service provided by the network, for example data volume, coverage area, or number of connections

throughput: number of payload bits successfully received per second for a reference measurement channel under a specified reference condition

NOTE: As defined in [i.8].

3.2 Symbols

Void.

3.3 Abbreviations

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

2G	Second Generation
3G	Third Generation
3GPP	3 rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
B2B	Business-to-Business
B2C	Business-to-Consumer
BS	Base Station
CO ₂ e	Carbon Dioxide equivalent
CoA	Coverage Area
CS	Circuit Switched
CSP	Communication Service Provider
DL	DownLink
DV	Data Volume
EC	Energy Consumption

EE	Energy Efficiency
eMBB	enhanced Mobile Broadband
eNB	evolved Node B
FDD	Frequency Division Duplex
FWA	Fixed Wireless Access
gNB	Next Generation Node B
HW	Hardware
ICT	Information and Communication Technologies
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Indicator
LTE	Long Term Evolution
MDEE	Multi-Dimensional Energy Efficiency
mMTC	massive Machine Type Communications
MN	Mobile Network
MNO	Mobile Network Operator
MTC	Machine Type Communication
NG-RAN	New Generation Radio Access Network
NR	New Radio
NSA	Non-Stand Alone
NTN	Non-Terrestrial Networks
O&M	Operation and Maintenance
OPEX	OPerational EXpenditures
O-RAN	Open RAN
OTT	Over The Top
PDCCP	Packet Data Convergence Protocol
QCI	QoS Class Identifier
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RLC	Radio Link Control
RRC	Radio Resource Control
RSRP	Reference Signal Received Power
SA	Stand-Alone
SDU	Service Data Unit
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
uRLLC	ultra-Reliable Low Latency Communication
VoLTE	Voice over LTE
VoNR	Voice over NR

4 Multi-dimensional network energy efficiency

A Mobile Network (MN) needs to fulfill several service requirements. It need to provide reliable coverage where the users want to access service, it need to provide enough capacity so that the traffic demand can be served, and it need to provide a service quality such that the users are satisfied with their experience of the service. Mobile Network Operators (MNOs) are continuously investing in their networks to make sure these service requirements, which evolve over time, are fulfilled. These investments are typically materialized in equipment consuming energy, and energy efficiency is an important objective. Energy efficiency is often defined as the useful output of a product or service divided by the energy consumption of the product or the service:

$$\text{Energy Efficiency} = \frac{\text{Useful work}}{\text{Energy consumption}}$$

A number of different energy efficiency metrics have been defined throughout the years, e.g. for mobile networks in ETSI ES 203 228 [i.1]. These network energy efficiency metrics are typically based on the amount of service provided, e.g. transported data volume, coverage area, or number of connections.