5TH GENERATION END-TO-END NETWORK, EXPERIMENTATION, SYSTEM INTEGRATION, AND SHOWCASING

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5GENESIS Test Cases

Companion Document

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0.2	Updated List of Authors, Delivery Date	G. Xilouris (NCSRD)	09/07/2020
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1.0	Final Release	M. Christopoulou (NCSRD)	

LIST OF ACRONYMS

Acronym	Meaning
5G	5^{th} Generation of cellular mobile communications
5G NR	5G New Radio
5G-PPP	5G Public-Private Partnership
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
ARM	Advanced RISC Machine
CN	Core Network
COAP	Constrained Application Protocol
COTS	Commercial-Off-The-Self
DL	Downlink
DRX	Discontinuous Reception
DUT	Device Under Test
DRAN	Distributed Radio Access Network
DWDM	Dense Wavelength Division Multiplexing
E2E	End-to-End
ELCM	Experiment Life Cycle Manager
eMBB	Enhanced Mobile Broadband - 5G Generic Service
EMS	Element Management System
EPC	Evolved Packet Core
E-UTRAN	Evolved Terrestrial Radio Access Network
FCAPS	Fault, Configuration, Accounting, Performance and Security
FPGA	Field Programmable Gate Array
GDPR	General Data Protection Regulation
HEVC	High Efficiency Video Coding
IaaS	Infrastructure as a Service
IED	Intelligent Electronic Devices
ING	Intelligent Network Gateway
IUG	Intelligent User Gateway
KPI	Key Performance Indicator
LOS	Line of Sight
LTE	Long Term Evolution
MANO	Management & Orchestration

MIMO	Multiple Input Multiple Output
MCPTT	Mission critical push-to-talk
MCS	Mission critical services
MME	Mobility Management Entity
mmWave	Millimetre Wave
NB-IoT	Narrow Band – Internet of Things
NFVO	Network Function Virtualization Orchestrator
NLOS	Non Line of Sight
NMS	Network Management System
NSA	Non-Stand-Alone
OAI	Over the Air Integration
OSS	Operational Support Services
PFCP	Packet Forwarding Control Protocol
PLMN	Public Land Mobile Network
PSM	Power Saving Mode
PTMP	Point-to-Multi-Point
QoE	Quality of Experience
QoS	Quality of Service
PTMP	point-to-multipoint
RAT	Radio Access Technology
REST	Representational State Transfer
RRH	Remote Radio Head
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTP	Real-time protocol
RTSP	Real-time Streaming Protocol
SA	Stand-Alone
SDK	Software Development Kit
SDN	Software Defined Networking
SINR	Signal to Interference plus Noise Ratio
SUT	System Under Test
TaaS	Testing as a Service
TAP	Test Automation Platform
TTN	The Things Network
UL	Uplink
UMA	University of Málaga

VIM	Virtual Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Function
VNFM	Virtual Network Function Manager
VPN	Virtual Private Network
VR	Virtual Reality
WIM	WAN Infrastructure Manager
WLAN	Wireless Local Area Network
WP	Work Package

Table of Contents

1 INTRODUCTION

1.1 Overview

This Companion Document consolidates and presents the Test Cases introduced by the 5GENESIS Consortium Partners in D6.1 “Trials and experimentation cycle 1” [11] and D6.2 “Trials and experimentation cycle 2”. It includes a brief description of the statistical processing methodology used during testing procedures as it was defined in D6.1 and provides the traffic profiles utilized during experimentation. Finally, for the sake of completeness, the document also includes the Sections of D6.1 regarding Energy Efficiency, providing a very detailed overview of the main standards and recommendations addressing Energy Efficiency KPIs on mobile networks.

The primary purpose of this document is to serve as a reference point for the experiments conducted during Cycle 2 by the 5GENESIS Consortium Facilities, which are presented in deliverable D6.2. Experimentation procedures in live mobile networks remains a complicated task, so this document is released in the hope of avoiding overwhelming the readers of D6.2. This Companion Document is based on requirements and specifications described in other 5GENESIS deliverables, summarized in Table 1:

Table 1 Document interdependencies

id	Document title	Relevance
D2.1 [1]	Requirements of the Facility	The document sets the ground for the first set of requirements related to supported features at the testbed for the facilitation of the Use Cases.
D2.2 [2]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [3] **Error! Reference source not found.**	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D3.1 [8]	Management and orchestration (Release A)	The document presents the MANO solutions that are integrated in the infrastructure. Interfaces and deployment options are also described.
D3.5 [4]	Monitoring and analytics	This document presents the methods and the framework for obtaining the statistical results for all the experiments in the deliverable

WP4 Del.	Athens D4.2 [5] Malaga D4.5 [6] Limassol D4.8 [7] Surrey D4.10 [9] Berlin D4.14 [10]	These documents describe the platform setup, capabilities and level of integration.
D6.1	Trials and Experimentation (cycle 1) [11]	This document is updated according to phase 2 evolution at the testbeds and coordination layer framework. The results were obtained using the D6.1 methodology and updated test descriptions and measurement procedures.

1.2 Target Audience

The primary target audience of this Companion document encompasses industry and standardization stakeholders, allowing them to validate the 5G KPIs, based on the description of the test cases and the subsequent experimentation results from the first integration cycle, providing the joint evaluation of the results obtained from the experiments in the different platforms.

As the approach is based on industry best practices, this deliverable is best suited for industry stakeholders, although not limited to them.

Other stakeholders that can benefit from the document include:

- Standardisation organizations
  Where the test cases can form the basis of test suites.
- European Commission
  To evaluate the conduction and results of 5G experimentation.
- Academic and research stakeholders
  As basis for design decisions for 5G based frameworks and applications development.
- Non-experts interested in 5G opportunities
  To understand the capabilities and limitations of 5G technology.

2 STATISTICAL PROCESSING METHODOLOGY

In the context of 5GENESIS, a single test case, focused on the evaluation of a KPI x in a predefined scenario (e.g., the evaluation of the throughput under specific network conditions), is repeated for a number of I iterations. Then, within the i^{th} iteration ($i = 1, \dots, I$), a number of N samples of the KPI are collected. A single KPI sample collected during the i^{th} iteration in the following is referred to as $x_{i,n}$ (with $n = 1, \dots, N$), while the entire set of samples collected during the same iteration is denoted by the vector $\boldsymbol{x}_i$. The statistical indicators for each iteration, are then computed, as reported in Table 2.

Table 2 Statistical indicators for a single iteration.

Indicator	Notation	Formula
Average (Mean)	$\bar{x}_i$	$\frac{1}{N}\sum_n x_{i,n}$
Standard deviation	$\sigma_{\boldsymbol{x}_i}$	$\sqrt{\frac{1}{N}\sum_n (x_{i,n} - \bar{x}_i)^2}$
Median	x_i^{med}	$\begin{cases} \left(\frac{N+1}{2}\right)\mathrm{th} & (N \text{ odd}) \\ \frac{\left(\frac{N}{2}\right)\mathrm{th} + \left(\frac{N+1}{2}\right)\mathrm{th}}{2} & (N \text{ even}) \end{cases}$ (Samples in ascending order, (a)th indicates the sample at the a^{th} position in the ordered vector)
p%-Percentile $0 < p \leq 100$	$x_i^{p\%}$	$\left(\left\lceil \frac{p}{100} \times N \right\rceil\right)\mathrm{th}$ (Samples in ascending order, (a)th indicates the sample at the a^{th} position in the ordered vector, $\lceil a \rceil$ indicates the ceiling operator (the least integer $\geq a$))))
Minimum	x_i^{min}	$\min(\boldsymbol{x}_i)$
Maximum	x_i^{max}	$\max(\boldsymbol{x}_i)$

The statistical indicators computed for each iteration are then used to compute the statistical indicators of the test case, for which the I iterations were executed. This is done by averaging the indicators for each iteration over the amount of iterations. Denoting as x_i^{stat} the generic statistical indicator for the i^{th} iteration, the corresponding value for the test case, x^{stat}, is then obtained as follows:

$$x^{\mathrm{stat}} = \frac{1}{I}\sum_i x_i^{\mathrm{stat}}$$

Moreover, since each statistical indicator of the test case is computed as an average over a limited amount of I samples, a t% Confidence Interval (CI) can be adopted to denote the precision of the provided outcome. In particular, the 95% CI is widely used, and defines an interval containing the true value of the sampled indicator, i.e., x^{stat}, with 95% probability. The

CI is usually evaluated using a Student-T distribution (in particular when the number of samples is low) with a number of degrees of freedom, denoted as v, equal to the number of available samples minus one, resulting in $v = I - 1$ in the present case [13]. The following indication, for each statistical indicator of the test case, can be then given as final outcome:

$$x^{\text{stat}} \pm t_{.95} \frac{\sigma_{x_i^{stat}}}{\sqrt{I}}$$

where:

- $t_{.95}$ is the so-called t value (or t score), which depends on the CI being evaluated (95 % in this case) and v, and can be derived from tabular approximations of the Student-T distribution;
- $\sigma_{x_i^{stat}}$ is the standard deviation of the vector $\boldsymbol{x}_i^{stat}$, containing the outcomes x_i^{stat} of the statistical indicator under analysis for each iteration, which are used to derive the corresponding indicator x^{stat} of the test case;
- $\frac{\sigma_{x_i^{stat}}}{\sqrt{I}}$ is the so-called standard error.

5GENESIS employs the Analytics Framework for the calculations described above. The Framework collects the data of the primary and complementary metrics recorded during the experiments and provides the statistical indicators of each metric. A sample output of the Analytics Framework for a Round trip Time experiment is demonstrated in Table 3:

Table 3 5GENESIS Analytics Framework Sample Output

```
******************************************

This Test Case includes 25 iterations! Statistical Analysis is performed, and results will be compliant to 5Genesis methodology.

******************************************

Test Case Statistics

Mean: 31.68 +/- 0.16 ms

Standard deviation: 5.97 +/- 0.10 ms

Median: 31.64 +/- 0.19 ms

Min: 20.97 +/- 0.68 ms

Max: 44.59 +/- 1.25 ms

25% Percentile: 26.64 +/- 0.18 ms

75% Percentile: 36.71 +/- 0.21 ms

5% Percentile: 22.55 +/- 0.17 ms

95% Percentile: 40.71 +/- 0.25 ms

******************************************
```

3 Test Cases

3.1 Capacity

The general metric of capacity refers to operational network deployments. Instead, considering the 5GENESIS Platforms' deployments, the Capacity KPI can be measured as "the total access network capacity of a single gNB over its corresponding radio-coverage area". The capacity is measured for both the uplink and the downlink. The coverage area will be calculated based on the 5G UE' sensitivity (average values or based on the radio equipment available at each platform).

At this point, it shall be noted that access network node capacity is a function of the available bandwidth and the average spectral efficiency. This is, the number of correctly received bits over a certain period of time divided by the channel bandwidth of a specific band divided by the number of Transmission-Reception Points (TRxPs), and it is measured in bit/s/Hz/TRxP[1].

Therefore, the evaluation of this KPI (with this metric) will include analytical methods or system-level simulations for the definition of the actual target per deployment[2] [3] [4] (and the comparison of the measured values from 5GENESIS Platforms against them), and the extrapolation of values measured from the 5GENESIS Platforms to other deployment configurations.

With similar restrictions and influencing factors, the Capacity KPI can be also measured by "the total access network capacity of a max. number of gNB that can be deployed over the corresponding total radio-coverage area".

3.1.1 Area Traffic Capacity

Test Case		*TC_CAP_AreaTrafficCapacity*	*Capacity*
1	*Target KPI* **Area traffic capacity** The KPI refers to the total traffic throughput served per geographic area (Mbps/m^2)[1] and is a measure of how much traffic a network can carry per unit area. It depends on the site density, bandwidth and average spectral efficiency.		

[1] Report ITU-R M.2410-0 (11/2017) Minimum requirements related to technical performance for IMT-2020 radio interface(s) https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

[2] Recommendations for NGMN KPIs and Requirements for 5G, NGMN Alliance, https://www.ngmn.org/fileadmin/user_upload/160603_Annex_-_NGMN_Liaison_to_3GPP_RAN__72_v1_0.pdf

[3] 5G Monarch, D_6_1 Documentation of Requirements and KPIs and Definitions of suitable Evaluation Criteria https://bit.ly/2YC4OhB

[4] Report ITU-R M.2412-0 (10/2017) Guidelines for evaluation of radio interface technologies for IMT-2020 https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2412-2017-PDF-E.pdf

	Methodology
2	In the ITU-R R M.2410-0 Report the area traffic capacity is calculated taking into account the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time. This can be derived for a particular use case (or deployment scenario) considering one frequency band and one Transmission Reception Point (TRxP) layer, based on the (i) achievable average spectral efficiency; (ii) network deployment, e.g., TRxP (site) density, and (iii) bandwidth. The TRxP is an antenna array with one or more antenna elements available to the network located at a specific geographical location for a specific area[5]. Let W denote the channel bandwidth and ρ the TRxP density (TRxP/m^2). The Area Traffic capacity C_{area} is related to the average spectral efficiency SE_{avg} through the following equation: $$C_{area} = \varrho(\frac{TRxP}{m^2}) \times W(Hz) \times SE_{avg}(\text{Bps/Hz/TRxP})$$ TRxP density ρ is the Number of TRxPs divided by the Area (m^2) over which the experimenter calculates the traffic capacity. The average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDU delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs. It is measured in bits/s/Hz/TRxP. The channel bandwidth for this purpose is defined as the effective bandwidth normalized appropriately considering the uplink/downlink ratio. The effective bandwidth is defined as: $$BW_{eff} = BW \times TR$$ where BW is the occupied channel bandwidth and TR is the time ratio of the link. In FDD systems, TR equals 1, while in TDD systems it depends on the downlink/uplink configuration. Let $R_i(T)$ denote the number of correctly received bits by user i (downlink) or from user i (uplink) in a system comprising a user population of N users and M TRxPs. Furthermore, let W denote the channel bandwidth and T the time over which the data bits are received. The average spectral efficiency is defined according to the following equation: $$SE_{avg} = \frac{\sum_{i=1}^{N} R\_i(T)}{T \cdot BW_{eff} \cdot M}$$ Based on the definitions above, the calculation of the area traffic capacity shall comprise the following steps: 1) Measure the aggregate throughput of all users on the PDCP Layer of the eNB. If this is not possible, then measure the aggregate throughput on the S1-U interface of the EPC. 2) Use the aggregate throughput in order to calculate the Average Spectral Efficiency. 3) Use the Average Spectral Efficiency to calculate the Area Traffic Capacity. Two cases are perceived for the creation of traffic in order to experimentally evaluate the area traffic capacity: (i) full buffer where traffic is generated and injected in the system using UDP protocol (ii) non-full buffer when TCP protocol is used for the generation of traffic.

[5] 3GPP TR 38.913 version 14.2.0 Release 14 5G; Study on Scenarios and Requirements for Next Generation Access Technologies

<table>
<tr><td></td><td>The simplified approach to be followed involves only downlink capacity. A single TRxP is defined in open space conditions. For the evaluation, a full 5G deployment is used, comprising a 5G UE, a 5G NR gNB and a 5G Core. A traffic generator capable of producing UDP or TCP traffic is used behind the N6 interface of the 5G system and a traffic sink that collects traffic is used at the UE side.</td></tr>
<tr><td>3</td><td>

Calculation process and output

The calculation process includes the following steps:

Let $\bar{R}(T)$ be the average aggregate throughput measured over a time interval T, and $R_n(T)$ be the average aggregate throughput measured at iteration n over a time interval T.

The reported Average Aggregate Throughput on the PDCP Layer on the eNB/gNB shall be calculated as follows:

$$Average\ Aggregate\ Throughput\ \bar{R}(T) = \frac{1}{N}\sum_{n=1}^{N} R\_n(T)$$

This value is used to calculate the Average Spectral Efficiency, leading to the Area Traffic Capacity.

The first-order statistics shall follow the 5GENESIS Statistical Processing Methodology.

The necessary calculations are shown in the following table:

<table>
<tr><th>Parameters</th><th>Formula</th></tr>
<tr><td>Effective Bandwidth (Hz)</td><td>$BW_{eff} = BW \times TR$</td></tr>
<tr><td>Average Aggregate Throughput (Mbps)</td><td>$\bar{R}(T) = \frac{1}{N}\sum_{n=1}^{N} R\_n(T)$</td></tr>
<tr><td>Average Spectral Efficiency(bit/s/Hz/TRxP)</td><td>$SE_{avg} = \frac{\bar{R}(T)}{BW_{eff} \times Number\ of\ Area\ TRxPs}$</td></tr>
<tr><td>Area (m^2)</td><td><Depends on the Area geometry></td></tr>
<tr><td>Site density (TRxP/m^2)</td><td>$\rho = \frac{Number\ of\ \mathrm{Area}\ TRxPs}{Area}$</td></tr>
<tr><td>Estimated average area traffic capacity (Mbps/m^2)</td><td>$C_{avg} = \rho\ \times W \times SE\_avg$</td></tr>
</table>

</td></tr>
<tr><td>4</td><td>

Complementary measurements

The experimenter should record the following complementary metrics during the measurement:

At the UE:

- *RSRP*
- *RSRQ*
- *SINR*

</td></tr>
</table>

	At the eNB/gNB: • *Uplink Signal Strength* • *CQI reported from UE*
5	*Pre-conditions* Prior to the beginning of the tests case: • The experimenter will define the area of interest and the UE locations for performing the measurements. • The UEs will be placed in various locations within the cell, including locations at the edge of the area (lowest possible SNR) to peak conditions (best possible SNR).
6	*Applicability* N/A
7	*Test Case Sequence* 1. Start recording the complementary metrics. 2. Initiate the traffic generator in the Downlink, using UDP traffic. 3. Set the duration of the measurement to 120s for 25 iterations. 4. Upon completing each measurement iteration, record the average throughput reported on the PDCP layer on the eNB. 5. Stop recording the complementary metrics. 6. Repeat steps 1-5 for TCP traffic. 7. Compute the area traffic capacity for each traffic case (UDP/TCP), as defined in the section “Calculation Process and Output”.

3.2 Density of Users

The fact that "density" is in general understood as "something that is measured" in relation to the area the measurement relates to – i.e. here, for density of users, giving results in the SI unit $1/m^2$) – imposes a special challenge for a test case: While the number of users served by a 5G-core over one or multiple base stations (BS) can be easily obtained as an operational parameter out of the packet core, quantizing the area the measurement relates to is not easily assessable. The coverage area of a single BS or small cell could be quantized, e.g.:

- by measuring the signal reception power at a several locations and then mapping them to an assumed availability of a service with specified QoS Class Identifier (QCI), thus obtaining the coverage area,
- via the theoretical coverage via propagation models or "best known results" from deployment experience,
- by quantizing the area that the users under concern within a measurement campaign reside in, acknowledging the fact that the actual coverage of the related radio cell may be larger.

To address this complexity within the measurement campaigns, 5GENESIS decided to define a set of test cases, each addressing either the number of devices served by a packet core, by a single or multiple gNBs, the number of gNBs deployable in a given region, or gauging the lower bound of geographical coverage for a given deployment. The resulting measurements hence allow to directly assess the density of users – in case the coverage area under concern is measured during an experiment - or to derive the density of users - in case the coverage area under concern is estimated. Table 4 provides examples for KPIs, which can be directly assessed in a test case and primarily measured.

Table 4 Density of users related KPIs

Metric	*Density of Users*
Number of devices that can be registered/simultaneously served (with traffic of specific QCI) per 5G-core element	#units
Max. number of devices that can be registered/simultaneously served (with traffic of specific QCI) in a 5G-Core solution (even if this requires dimensioning of one or more components of it)	#units
Max. number of devices that can be registered/simultaneously served (with traffic of specific QCI) by a single gNB	#units
Max. number of devices that can be registered/simultaneously served (with traffic of specific QCI) by the total number of gNBs that can be connected to a 5G-Core solution	#units
Max. number of gNB that can be deployed over the corresponding total radio-coverage area.	#units/m^2
Max. number of devices that can be registered/simultaneously served in a 5G-Core providing network service (via gNBs or n3GPP XS technologies) for a well-known geographical region.	#units/m^2

3.2.1 Maximum number of devices registered per Packet-core

Test Case		TC_DEN_MaxRegisteredUE_BER_001	*Density of Users*
1	*Target KPI* ***Maximum number of devices registered per Packet Core*** This KPI refers to the maximum number of devices (UEs), which a packet core can support. It hence provides information on the upper bound of the density of users per unit area as regardless of how the coverage area is optimized within a given system, the core cannot support more users than obtained via this measurement. This test case isolates against the potential impact of the behaviour of the UEs or BSs on the results; the SUT is the pure packet core and the measurement tools used to communicate with the core replicate the interface between the packet core and a BS. Source A → Test tool / instrument emulating UE, gNB behaviour towards the packet core (N:1/N:2 interface) Destination B → AMF of packet core Underlying system → 5G packet core		
2	*Methodology* To measure the maximum number of devices that can register per packet core, a set of consecutive experiments are run. In each experiment the number of UEs registering at the packet core is constantly increased, up to the point at which the registration process fails or takes longer than a predefined, set upper time limit. Then, the maximum number of devices that can register is given by the maximum of the number of UEs in the set of experiments for which the registration is successful and completed before the predefined, set upper time limit. Hence, a single iteration consists of several consecutive steps. They are characterized by an increasing number of UE registering to the packet core. Several replica of an iteration shall be conducted to gain confidence values for reported results. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → given by termination criteria, i.e.: terminate iteration when (a) at least one registration attempt within a single step of the iteration fails or (b) when the time required to conduct all scheduled registrations within a step exceed a given threshold. • Number of UEs to be simulated → **U** • Operations per second (target attachment rate) → **R** • Timeout value for a step within an iteration → $T_{timeout} = 1.5 * \max(100\ ms*U, U/R)$ • Number of replica (iterations) → **N** >= 25		
3	*Calculation process and output* The required results shall be calculated according to the following methodology: Let max_i be the maximum number of devices that can be registered as observed in the i^{th} iteration; and let $x_{i,n}$ be the number of UEs in the i^{th} step within a trial as such that all registration succeed and as such that all registration complete the timeout for that trial; and let $x_{i+1,n}$ be the number of UEs in the $(i+1)^{th}$ step within a trial as such that at least one registration fails or as such that		

	the registrations take more than the timeout to complete, then **max**$_i$ is given by: $$max_i = x_{i,n}$$ The maximum number of devices that can be registered shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* Average latency of UE registration
5	*Pre-conditions* A deployed and working 5G packet core (SUT) to which the testing tool (emulating UE and gNB behaviour) may connect to. No registered UEs in the system.
6	*Applicability* This test case applies for all scenarios that evaluate the performance of a packet core.
7	*Test Case Sequence* 1. Assure the precondition is met, i.e. there are no registered UE in the system 2. Set the test tool to emulate **U** number of UE, which attempt to register at the packet core, to 50 (Initial value). 3. set the test tool to run consecutive registration requests of the UE towards the packet core at a rate of **R**=100 Hz. 4. Report the time to complete step (2). 5. if (a) all registrations succeeded and (b) if the recoded time is less than the set timeout value. i. Deregister all UE at the packet core ii. Increase **U** by 50 iii. Repeat this test sequence from step (3) onwards 6. Deregister all UE and terminate the iteration. 7. Repeat steps 1 to 6 N times 8. Compute the KPIs as defined in section “Calculation process and output”.

3.2.2 Maximum number of active UE per Packet-core

Test Case		TC_DEN_MaxActiveUE_BER	Density of Users
1	*Target KPI* **Maximum number of active devices per Packet Core** This KPI refers to the maximum number of active devices (UE), which a packet core can support. It hence provides information on the upper bound of the density of users per unit area under the constraint of considering only active users, as regardless of how the coverage area is optimized within a given system, the core cannot support more simultaneously active users than obtained via this measurement. This test case is designed to only focus on the maximum number of active users a packet core can support, and not as a stress test in terms of experiencing a high signalling rate of UE going from idle into active mode. This test case isolates against the potential impact of the behaviour of UE or BS on the results; the system under test is the pure packet core and the measurement tools used to communicate with the core replicate the interface between the packet core and a BS. Source A → Test tool / instrument emulating UE, gNB behaviour towards the packet core (N:1/N:2 interface) Destination B → AMF of packet core Underlying system → 5G packet core		
2	*Methodology* To measure the maximum number of active devices per packet core, a set of consecutive experiments are run, as such that in each experiment the number of UE going from idle into active mode is constantly increased. The number of UE switching into active mode is increased up to the point at which the signalling fails or takes longer than a predefined, set upper time limit. Then, the maximum number of active devices that a packet core can support is given by the maximum number of UE in the set of experiments for which the transition from idle into active mode is successful and completes before the predefined, set upper time limit. Hence, a single iteration of the experiment consists of several consecutive steps being characterized by an increasing number of UE requesting the packet core to switch from idle into active mode. Several replicas of an iteration shall be conducted to gain confidence values for reported results. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → given by termination criteria, i.e.: terminate iteration when (a) at least one UE is denied to switch into active mode, or the signalling fails within a single step of the iteration or (b) when the time required to conduct all scheduled registrations within a step exceed a given threshold. • Number of UEs to simulate → U • Operations per second (target attachment rate) → R • Timeout value for a step within an iteration → $T_{timeout}$ = 1.5 * max(100 ms*U , U/R) • Number of replica (iterations) → N >= 25		

3	*Calculation process and output* The required output should be calculated according to the following methodology: Let **max**$_i$ be the maximum number of devices that can be simultaneously active as observed in the ith iteration; and let **x**$_{i,n}$ be the number of UE in the ith step within a trial such that all UE successfully transfer into active mode and all UE activations complete within the timeout for that trial; and let **x**$_{i+1,n}$ be the number of UE in the i+1th step within a trial as such that at least one request of a UE to switch into active mode fails or as such that the registrations take more than the timeout to complete, then **max**$_i$ is given by: $$max_i = x_{i,n}$$ Then, the overall (reported) maximum number of active devices that a packet core can support **max** shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* • Average duration of UE activation time
5	*Pre-conditions* A deployed and working 5G packet core (SUT) to which the testing tool (emulating UE and gNB behavior) may connect to. A number of UE are registered at packet core, but are idle. This number shall be set to the maximum number of registered UE by a packet core as identified by test case *TC_DEN_MaxRegisteredUE_BER_001*. Zero active UE in the packet core.
6	*Applicability* This test case applies for all scenarios that evaluate the performance of a packet core.
7	*Test Case Sequence* 1. Assure the precondition is met, i.e. there is no active UE in the system and there are a number of registered UE in the system, where the number is the maximum number of registered UE 2. Set the test tool to emulate **U** number of UE, which attempt to transition into active mode, to 50 (Initial value) 3. set the test tool to run consecutive activation requests of the UE towards the packet core at a rate of **R** = 100Hz 4. Report the time to complete step (2) 5. if (a) all activations succeeded and (b) if the recoded time is less than the set timeout value. • Increase by 50 the number of UE in the test tool, which attempt to become active, and • Deactivate all UEs at the packet core and assure that the preconditions are met • Repeat this test sequence from step (3) onwards 6. Deregister all UE and terminate the iteration 7. Repeat steps 1 to 6 for **N** iterations 8. Compute the KPIs as defined in section “Calculation process and output”

3.2.3 Number of Operation Requests processed per Second

Test Case		*TC_DEN_MaxNumOperationReqProcessed_BER*	*Density of Users*
1	*Target KPI* ***Maximum number of operations per second per Packet Core*** This KPI refers to the maximum number of operation requests processed per second (Op/s), which a packet core can support. It hence provides information on the upper bound of the density of users per unit area as regardless of how the coverage area is optimized within a given system, the core cannot support more users than obtained via this measurement. This test case isolates against the potential impact of the behaviour of the UEs or BSs on the results; the SUT is the pure packet core and the measurement tools used to communicate with the core replicate the interface between the packet core and a BS. Source A → Test tool / instrument emulating UE, gNB behaviour towards the packet core (N:1/N:2 interface) Destination B → AMF of packet core Underlying system → 5G packet core		
2	*Methodology* To measure the maximum number of operations per second that a packet core can process, a set of consecutive experiments are run. In each experiment the number of operations sent to the packet core is increased, up to the point at which the registration process fails or takes longer than a predefined, set upper time limit. Then, the maximum number of operations/s is given by the maximum of operations/s in the set of experiments for which the registration is successful and completed before the predefined, set upper time limit. Hence, a single iteration consists of several consecutive steps. They are characterized by an increasing number of operations requested to the packet core per second. Several replica of an iteration shall be conducted to gain confidence values for reported results. The test case shall include the consecutive execution of several iterations according to the following properties: • Duration of a single iteration → given by termination criteria, i.e.: terminate iteration when (a) at least one registration attempt within a single step of the iteration fails or (b) when the time required to conduct all scheduled registrations within a step exceed a given threshold. • The number of operation requests per second → **R** • UE attachment/detachment requests → **U** • Timeout value for a step within an iteration $\mathbf{T_{timeout}}$ • Number of replica (iterations) → **N** >= 25 iterations		
3	*Calculation process and output* The required results should be calculated according to the following methodology: Let $\mathbf{max_i}$ be the maximum number of devices that can be registered as observed in the i^{th} iteration; and let **ops_(i,n)** be the number of operations per second in the i^{th} step within a trial, as such that all registrations succeed and as such that all registrations complete before the timeout for that trial; and let **ops_(i+1,n)** be the number of operations per second in the $i+1^{th}$ step within a trial,		

	as such that at least one registration fails or as such that the registrations take more than the designated timeout to complete, then **max**$_i$ is given by: $$max_i = ops_{i,n}$$ The maximum number of operation requests that can be processed by a core network **max** shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* Average duration of UE registration and deregistration time
5	*Pre-conditions* A deployed and working 5G packet core (SUT) to which the testing tool (emulating UE and gNB behaviour) may connect to. No registered UEs in the system.
6	*Applicability* This test case applies for all scenarios that evaluate the performance of a packet core.
7	*Test Case Sequence* 1. Assure the precondition is met, i.e. there are no registered UE in the system 2. Set the test tool to emulate **R** number of operations per second, which attempt to register at the packet core, to 1/s (Initial value). 3. Set the test tool to run consecutive registration requests of the UE towards the packet core with a constant number of emulated UE registrations. 4. Report the time to complete step (2). 5. If (a) all registrations succeeded and (b) if the recoded time is less than the set timeout value. i. Deregister all UE at the packet core and assure that no UE is registered in the core. ii. Increase the number of operations per second **R** in the test tool. iii. Repeat this test sequence from step (3) onwards 6. Deregister all UE and terminate the iteration. 7. Repeat steps 1 to 6 for **N** iterations. 8. Compute the KPIs as defined in section “Calculation process and output”.

3.2.4 Average Operation Processing Delay

Test Case		*TC_DEN_OperProcessingDelay_BER*	*Density of Users*
1	*Target KPI* ***Average operation processing latency of a packet core*** This KPI refers to the average latency of the user equipment operation request processing at a Core Network. It hence provides information on the upper bound of the density of users per unit area as regardless of how the coverage area is optimized within a given system. This test case isolates against the potential impact of the behaviour of the UEs or BSs on the results; the SUT is the pure packet core and the measurement tools used to communicate with the core replicate the interface between the packet core and a BS. Source A → Test tool / instrument emulating UE, gNB behaviour towards the packet core (N:1/N:2 interface) Destination B → AMF of packet core Underlying system → 5G packet core		
2	*Methodology* To measure the average latency of user operation processing per packet core, a set of consecutive experiments are run. The average processing latency depends on several parameters: the number of UEs registering at the packet core, the number of operations requested per second and the computational resources available to the core network functions. Several replicas of an iteration shall be conducted to gain confidence values for reported results. The test case shall include the consecutive execution of several iterations according to the following properties. • Number of UEs to be simulated → U • Operations per second (target attachment rate) → R • Number of replica (iterations) → N >= 25		
3	*Calculation process and output* The average number of operations shall be calculated according to the 5GENESIS Statistical Processing Methodology.		
4	*Complementary measurements* Average latency of UE registration and deregistration processing.		
5	*Pre-conditions* A deployed and working 5G packet core (SUT) to which the testing tool (emulating UE and gNB behaviour) may connect to. No registered UEs in the system.		

6	*Applicability* This test case applies for all scenarios that evaluate the performance of a packet core.
7	*Test Case Sequence* 1. Assure the precondition is met, i.e. there are no registered UE in the system 2. Set the test tool to emulate U number of UE, which attempt to register at the packet core. 3. Set the test tool to run consecutive registration requests of the UE towards the packet core at a rate of R. 4. Report the time to complete step (2). 5. Deregister all UE and terminate the iteration. 6. Repeat steps 1 to 5 for N iterations. 7. Compute the KPIs as defined in section "Calculation process and output".

3.2.5 Maximum number of devices registered per Packet-core 2

Test Case		TC_DEN_MaxRegisteredUE_BER_002	Density of Users
1	*Target KPI* ***Maximum number of devices registered per Packet Core 2*** This KPI refers to the maximum number of devices (UEs), which a packet core can support. It hence provides information on the upper bound of the density of users per area unit. Regardless of how the coverage area is optimized within a given system, the core cannot support more users than obtained via this measurement. This test case isolates against the potential impact of the behaviour of the UEs or BSs on the results; the SUT is the pure packet core and the measurement tools used to communicate with the core replicate the interface between the packet core and a BS. Source A → Test tool / instrument emulating UE, gNB behaviour towards the packet core (N:1/N:2 interface) Destination B → AMF of packet core Underlying system → 5G packet core		
2	*Methodology* To measure the maximum number of devices that can register per packet core, a set of consecutive experiments are run. In each experiment the test tool attempts to register virtual UEs at the packet core, up to an arbitrary upper limit (best estimate). Then, the maximum number of devices that can register is given by the maximum of the number of successful registrations. Hence, a single iteration consists of several consecutive steps. Several replica of an iteration shall be conducted to gain confidence values for reported results. The test case shall include the consecutive execution of several iterations according to the following properties. Number of UE simulated to register at the core network → **U** Operations per second (target attachment rate) → **R** = 100 Hz Timeout value for a step within an iteration → 1.5 * max(100 ms***U** , **U**/**R**) Number of replica (iterations) → **N** >= 25		
3	*Calculation process and output* The maximum number of devices that can be registered successfully shall be calculated according to the 5GENESIS Statistical Processing Experimentation Methodology.		
4	*Complementary measurements* Average duration of UE registration time		

5	*Pre-conditions* A deployed and working 5G packet core (SUT) to which the testing tool (emulating UE and gNB behaviour) may connect to. No registered UEs in the system.
6	*Applicability* This test case applies for all scenarios that evaluate the performance of a packet core.
7	*Test Case Sequence* 1. Assure the precondition is met, i.e. there are no registered UE in the system 2. Set the test tool to emulate the number of UE to register at the packet core **U**, to the upper limit. 3. Set the test tool to run consecutive registration requests of the UE towards the packet core at a rate of **R**=100 Hz. 4. if (a) all registrations succeeded, increase **U** by an amount large enough to potentially exceed the maximum amount in the next iteration. 5. Deregister all UE and terminate the iteration. 6. Repeat steps 1 to 5 for **N** iterations. 7. Compute the KPIs as defined in section "Calculation process and output".

3.3 Energy Efficiency

3.3.1 Average Energy Efficiency

Test Case		TC_ENE_RANEnergyEfficiencyAVG	Energy Efficiency
1	*Target KPI* **Average RAN Energy Efficiency** This KPI aims to measure the RAN EE and represents the efficiency with which each Joule of energy is used to transmit information. This KPI expression represents the data volume of the BSs under consideration, divided by the total EE of the BS sites (including the support infrastructure).		

2	*Methodology*
	For the evaluation, a full 5G deployment composed of a 5G UE (or UE emulator), a 5G NR gNB and 5G core is used. A traffic generator capable of producing UDP or TCP traffic is used behind the N6 interface of 5G system and a traffic sink that collects traffic is used at the UE side.
	The generated traffic is using full length IP packets (i.e. 1500bytes) and the baseline measurement duration is 24 hours (experiment repeated for 7-days). The data volume will be collected via NMS counters and energy consumption through measurements (using watt meters or from utility provider).
	The test case shall include the consecutive execution of several replica (iterations) according to the following properties.
	• Duration of a single replica (iteration) → at least 15 minutes
	  ○ Note, that there will be a max. of 24*60 / 15 = 96 iterations over a 24-hour period, therefore the min. # iterations over a single 24-hour period is set to 96/8 = 12.
	• Number of replica (iterations) → At least 12 x 7 = 84
	  ○ Note that "experimentation" period (for final results reporting) covers a period of 7-days.		

3	Calculation process and output **EC Measurement** The MN EC (EC_{MN}) is the sum of the EC of equipment included in the MN under investigation. The network ECZ is measured according to the assessment process defined in section 6 of [16] such that individual metrics are provided per RAT and per MNO. **The overall EC of the partial MN 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_{MN} is EC, in the MN under test, and is measured in Watts/hr.[6] (Wh = Joule), over the period of measurement T. • BS refers to the BSs in the MN under measurement.		

[6] 1 Wh = 3·6 KJ

- 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 EC of the various segments e.g. BS, BH, CR etc. can be measured by means of metering information provided by utility suppliers or by mobile network integrated measurement systems. EC_{MN} is measured in unit of Wh (Watt Hours). Power consumption and EE measurements of individual MN elements are described in several standards e.g., ITU-T L.1310 [22] for radio base stations and ITU-T L.1320 [40] for power and cooling equipment. When a mobile network integrated measurement system according to ETSI ES 202 336-12 [30] is available, it should be used in addition to the utility provided EC allowing a more precise estimation of the consumption per RAT and per MNO.

DV Measurement

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

For PS services, DV_{MN} is defined as the DV delivered by the equipment of the partial MN under investigation during the time frame T of the EC assessment. The assessment process defined in section 6 shall be used:

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

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

For CS services[7] like voice, DV_{MN-CS} is defined as the DV delivered by the equipment of the MN under investigation during the time frame T of the EC assessment:

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

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

The overall data volume is computed as follows:

$$DV_{MN} = DV_{MN-PS} + DV_{MN-CS} \qquad (4)$$

DV_{MN} can be derived based on standard counters defined in ETSI TS 132 425 [18] for LTE (or 3GPP equivalent: TS 32.425), multiplying by the measurement duration T. DV_{MN} is computed in unit of bit.

For PS traffic, the DV is considered as the overall amount of data transferred to and from the users present in the MN under test. DV shall be measured in an aggregated way per each RAT present in the MN and shall be measured referring to counters derived from vendor O&M systems.

[7] Note that "circuit switched", refers to all voice, interactive services and video services managed by the MNOs, including CS voice and real-time video services delivered through dedicated bearers.

	For CS traffic, the DV 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[8]. The call success rate is equal to 1 minus the sum of blocking and dropping rates, i.e.: $$Call\ Success\ Rate = (1 - dropping\ rate) \times 100\ [\%] \quad (5)$$ 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: $$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \quad (6)$$ In order to include reliability in the measurement the aggregated DV shall be provided together with the 95th percentile of the cumulative distribution, for each RAT in the MN. For data reporting, templates available in ANNEX A in ETSI ES 203 228 [17] (or equivalents i.e. ANNEX I of Rec. ITU-T L.1331 [23] or in 3GPP TR 32.856 [29]) are used. **OUTPUTs:** i)The *KPI*$_{EE\text{-}capacity}$ ($EE_{MN,DV}$), expressed unit of “bits/Joule” [equivalent to bits/Watt hour (Wh)]., is calculated as the ratio between the DV (DV_{MN}) and the EC (EC_{MN}), in the MN, during the 7-day measurement period: $$EE_{MN,\ DV} = DV_{MN} / EC_{MN} \quad (7)$$ i)The *KPI*$_{EE\text{-}site}$ (denoted as SEE) expressed in unit of “Wh” [Watt hour], is calculated as the ratio of the EC of the telecom equipment to the total EC: $$SEE = EC_{BSs}/(EC_{BSs} + EC_{SI}) \quad (8)$$ Where, EC_{BSs} represents EC of BSs under test site, and EC_{SI} represents EC of supporting infrastructure, during the 7-day measurement period. i)The **mean** (observed over the measurement period) values of $EE_{MN,DV}$ and SEE,will be reported. The required results should be calculated according to the following methodology: Let EEavg_i be the calculated average EE for the ith iteration, and x_(i,n) be the measured EE for each iteration: $$EEavg_i = \frac{1}{n}\sum_n x_{i,n}$$ Then, the overall (reported) average EE*mean* shall be calculated as the average of all x_i $$EEmean = \frac{1}{i}\sum_i EEavg_i$$ For the overall average EE (EEmean), the 95 % confidence interval shall be reported using the Student-T-distribution for *v = i - 1* degrees of freedom to denote the precision of the experiment.
4	*Complementary measurements* *The following complementary metrics will be available and logged during the measurement period:*

[8] Note that for CS traffic in LTE RAT, there are no measurements defined in TS 32.425. for calculation of CS traffic refer to Table 4.4.3.2-2, in [29].

	At the UE: • *RSRP* • *RSRQ* • *SINR* *At the eNB/gNB:* • *Uplink Signal Strength* • *CQI reported from UE*
5	*Pre-conditions* The experimenter will define the following parameters of each setup: • Technology/Band • Transmission Mode (TDD/FDD) • Receive/Transmit Frequencies • Number of Antennas • Channel Bandwidth • UE Category • Service/slice configuration (eMBB, URLLC etc.) Prior to the beginning of the tests: • The experimenter will define the (designated) area of interest, size of “partial network under test” [unit: # sites], number of UE, and the UE locations (random deployment) • The UE will be placed in various locations within the cell, including locations at the edge of the area (lowest SNR). • There will be only one or more UEs (or UE emulator) successfully attached to the network.
6	*Applicability* The UE and eNB/gNB should provide monitoring of the Complementary metrics.
7	*Test Case Sequence* 1. Start recording the complementary metrics. 2. Initiate the traffic generator in the Downlink and Uplink, using UDP traffic. 3. Set the period of the measurement to 24 hrs. 4. Stop recording the complementary metrics at end of measurement period. 5. Upon completing the measurement, record the DV_{MN} based on NMS counters & eq. (1). 6. Upon completing the measurement, record the EC_{MN} & apply eq. (4). 7. Repeat Steps 1-6 for period of 7 days. 8. Compute the weekly EE KPI based on eq. (7) and (8). Extend to yearly, using extrapolation method. 9. Report the MN EE assessment results for 4G and 5G deployments separately, using the KPIs definition provided in section "Calculation process and output" as well as the templates provided in Sections 4,5 and 6 of this document.

3.3.2 Peak Energy efficiency

Test Case		TC_ENE_RANEnergyEfficiencyMAX	Energy Efficiency
1	*Target KPI* **RAN Energy Efficiency** This KPI aims to measure the RAN EE and represents the efficiency with which each Joule of energy is used to transmit information. This KPI expression represents the data volume of the BSs under consideration, divided by the total EC of the BS sites (including the support infrastructure).		
2	*Methodology* For the evaluation, a full 5G deployment composed of a 5G UE (or UE emulator), a 5G NR gNB and 5G core is used. A traffic generator capable of producing UDP or TCP traffic is used behind the N6 interface of 5G system and a traffic sink that collects traffic is used at the UE side. The generated traffic uses full length IP packets (i.e. 1500 bytes) and the baseline measurement duration is 24 hours (experiment repeated for 7 days). The data volume is collected via NMS counters and EC through measurements (using watt meters or from utility provider). The EE can be measure based on the following KPIs: • $KPI_{EE\text{-}capacity}$ (used to measure EE, on the basis of EC in relation to capacity), • $KPI_{EE\text{-}site}$ (used to measure the EE of the support infrastructures of the site as compared to the consumption of the BS(s) of the site). The KPIs are applicable to all stages of network utilization. However, it has to be recognized that as the BS utilization increases: • $KPI_{EE\text{-}capacity}$ will increase, since the BS equipment operates more efficiently at higher load levels • $KPI_{EE\text{-}site}$ will increase. The $KPI_{EE\text{-}capacity}$ ($EE_{MN,DV}$), expressed in bit/J, is defined as the ratio between the Data Volume (DV_{MN}) and the EC (EC_{MN}), in the MN: $$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}}$$ As the KPI is measured in unit of “bits/Joule” [equivalent to bits/Watt hour (Wh)] it represents the efficiency with which each Joule of energy is used to transmit information. This KPI expression represents the data volume of the BS over the backhaul network divided by the total EC of the BS site (including the support infrastructure). The EC_{MN} includes EC of each BS of the BS site as well as that of the support infrastructure of the BS site, during the measurement period. This KPI is used for MNs handling high data volumes, in particular in dense-urban, urban areas (i.e. capacity-limited deployments). The $KPI_{EE\text{-}site}$, denoted as SEE, expressed in “Wh”, is an additional network KPI describing the EC of the telecom equipment with reference to the total EC: $$SEE = \frac{EC_{BSs}}{EC_{BSs}+EC_{SI}}$$		

	EC_{BSs} represents EC of BSs under test site, and EC_{SI} represents EC of supporting infrastructure, during the measurement period.
	
	The SEE metric provides an INDICATION of SEE in terms of how big a fraction of total energy is used for actual telecom equipment (telecommunication service delivery). In other words, it provides the EC overhead incurred due to the BS site support infrastructure/equipment.
	
	The KPI definitions follow the recommendations in ITU-T L.1331 [23] and ETSI Standard ES 203 2289 [17], (which are technically equivalent), and describe the EC and MN EE measurements in operational networks.
	
	Note: the data vol. and EE measurements will be performed on a sub-network i.e. a selection of BS sites which constitutes *the partial MN under test*. The ETSI ES 203 228 [17] section 7, defines a method to extrapolate the measured EE KPIs of **the partial MN under test** to the operator's whole RAN.
	
	The test case shall include the consecutive execution of several replica (iterations) according to the following properties.
	
	• Duration of a single replica (iteration) → at least 15 minutes
	    ○ Note, that there will be a max. of 24*60 / 15 = 96 iterations over a 24-hour period, therefore the min. # iterations over a single 24-hour period is set to 96/8 = 12.
	• Number of replica (iterations) → At least 12 x 7 = 84
	    ○ Note that "experimentation" period (for final results reporting) covers a period of 7-days.

3	*Calculation process and output* **EC Measurement** The MN EC (EC_{MN}) is the sum of the EC of equipment included in the MN under investigation. The network EC is measured according to the assessment process defined in section 6 of [16] such that individual metrics are provided per RAT and per MNO. **The overall EC of the partial MN under test** is measured as follows: $$EC_{MN} = \sum_i \left(\sum_k EC_{BS_{i,k}} + EC_{SI_i}\right) + \sum_j EC_{BH_j} + \sum_l EC_{RC_l}$$ where: • EC_{MN} is EC, in the MN under test, and is measured in Watts/hr.[10] (Wh = Joule), over the period of measurement T. • BS refers to the BSs in the 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.

[9] ITU-T L.1331/1330 and ETSI Standard ES 203 228 describes EC and MN EE measurements **in operational networks**, whilst power consumption and EE measurements of **individual MN elements** are described in several standards (e.g. ETSI ES 202 706 **Error! Reference source not found.** for radio base stations).
[10] 1 Wh = 3·6 KJ

- l is the index spanning over the control nodes of the MN.

The EC of the various segments e.g. BS, BH, CR etc. can be measured by means of metering information provided by utility suppliers, COTS tools e.g. smart-meter plugs [41] or by MN integrated measurement systems. EC_{MN} is measured in unit of Wh (Watt Hours). Power consumption and EE measurements of individual MN elements are described in several standards e.g., ITU-T L.1310 [22] for radio base stations and ITU-T L.1320 [40] for power and cooling equipment. When a MN integrated measurement system according to ETSI ES 202 336-12 [30] is available, it should be used in addition to the utility provided EC allowing a more precise estimation of the consumption per RAT and per MNO [41].

Data Volume (DV) Measurement

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

For packet switched services, DV_{MN} is defined as the data volume delivered by the equipment of the partial MN under investigation during the time frame T of the EC assessment. The assessment process defined in section 6 shall be used:

$$DV_{MN-PS} = \sum_{i,k} DV_{BS_{i,k}-PS}$$

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

For circuit switched services[11] like voice, DV_{MN-CS} is defined as the data volume delivered by the equipment of the MN under investigation during the time frame T of the EC assessment:

$$DV_{MN-CS} = \sum_{i,k} DV_{BS_{i,k}-CS}$$

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

The overall data volume is computed as follows:

$$DV_{MN} = DV_{MN-PS} + DV_{MN-CS}$$

DV_{MN} can be derived based on standard counters defined in ETSI TS 132 425 [18] for LTE (or 3GPP equivalent: TS 32.425), multiplying by the measurement duration T. DV_{MN} is computed in unit of bit.

For packet switch (PS) traffic, the data volume is considered as the overall amount of data transferred to and from the users present in the MN under test. Data volume shall be measured in an aggregated way per each RAT present in the MN and shall be measured referring to counters derived from vendor O&M systems.

For Circuit Switch (CS) traffic, 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[12]. The call success rate is equal to 1 minus the sum of blocking and dropping rates, i.e.:

[11] Note that "circuit switched", refers to all voice, interactive services and video services managed by the MNOs, including CS voice and real-time video services delivered through dedicated bearers.

[12] Note that for CS traffic (e.g. VoLTE) in LTE RAT, there are no measurements defined in TS 32.425. for calculation of CS traffic refer to Table 4.4.3.2-2, in [28].

$$Call\ Success\ Rate = (1 - dropping\ rate) \times 100\ [\%] \quad (5)$$

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:

$$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \quad (6)$$

In order to include reliability in the measurement the aggregated data volume shall be provided together with the 95th percentile of the cumulative distribution, for each RAT in the MN.

For data reporting, templates available in ANNEX A in ETSI ES 203 228 [17] (or equivalents i.e. ANNEX I of Rec. ITU-T L.1331 [23] or in 3GPP TR 32.856 [29]) are used.

OUTPUTs:

v)The $KPI_{EE\text{-}capacity}$ (denoted as $EE_{MN,DV}$ below), expressed unit of "bits/Joule" [equivalent to bits/Watt hour (Wh)]., is calculated as the ratio between the Data Volume (DV_{MN}) and the Energy Consumption (EC_{MN}), in the mobile network (MN), during the 7-day measurement period:

$$EE_{MN,DV} = DV_{MN} / EC_{MN} \quad (7)$$

v)The $KPI_{EE\text{-}site}$ (denoted as SEE) expressed in unit of "Wh" [Watt hour], is calculated as the ratio of the energy consumption of the telecom equipment to the total energy consumption:

$$SEE = EC_{BSs}/(EC_{BSs} + EC_{SI}) \quad (8)$$

where, EC_{BSs} represents energy consumption of BSs under test site, and EC_{SI} represents energy consumption of supporting infrastructure, during the 7-day measurement period.

i)The **peak** (observed over the measurement period) values of $EE_{MN,DV}$ and SEE will be reported.

The required peak output should be calculated according to the following methodology:

Let EEmax_i be the maximum EE measured in the ith iteration, and x_(i,n) be the measured EE for each sinle 15-min. iteration:.

$$EEmax_i = \max(x_{i,n})$$

Then, the (reported) maximum EE (EEpeak) shall be calculated as follows:

$$EEpeak = \frac{1}{i} \sum_i EEmax_i$$

For the reported maximum EE (EEpeak), the 95% confidence interval shall be reported using the Student-T-distribution for *v = i - 1* degrees of freedom to denote the precision of the experiment.

4

Complementary measurements

The following complementary metrics will be available & logged during the measurement period:

At the UE:

- *RSRP*
- *RSRQ*
- *SINR*

At the eNB/gNB:

- *Uplink Signal Strength*
- *CQI reported from UE*

5	*Pre-conditions* The experimenter will define the following parameters of their setup: • Technology/Band • Transmission Mode (TDD/FDD) • Receive/Transmit Frequencies • Number of Antennas • Channel Bandwidth • UE Category • Service/slice configuration (eMBB, URLLC, etc.) Prior to the beginning of the tests: • The experimenter will define the (designated) area of interest, size of “partial network under test” [unit: # sites], number of UEs, and the UE locations (random deployment) • The UEs will be placed in various locations within the cell, including locations at the edge of the area (lowest SNR). There will be only one or more UE (or UE emulator) successfully connected to the network. Measurements shall be performed without any energy savings features to evaluate basic RAN energy efficiency.
6	*Applicability* The UE and eNB/gNB should provide monitoring of the Complementary metrics.
7	*Test Case Sequence* 1. Place UEs (operating in NSA mode) in a test location corresponding to good coverage. 2. Start recording the complementary metrics. 3. Initiate the traffic generator in the Downlink & Uplink, using UDP traffic. 4. Set the period of the measurement to 24 hrs. 5. Stop recording the complementary metrics at end of measurement period. 6. Upon completing the measurement, record the DV_{MN} based on NMS counters & eq. (1). 7. Upon completing the measurement, record the EC_{MN} from utility meters/watt meters & apply eq. (4). 8. Repeat Steps 1-6 for period of 7 days. 9. Compute the weekly EE KPI based on eq. (7) and (8). Extend to yearly, using extrapolation method in [x]. 10. Report the MN EE assessment results for 4G and 5G deployments separately, using the KPIs definition provided in section "*Calculation process and output*", as well as the templated provided in Sections 4, 5 and 6 of this document.

3.3.3 UE Energy Efficiency

Test Case		*TC_ENE_UEEnergyEfficiency*	*Energy Efficiency*
1	*Target KPI* **UE Energy Efficiency** This KPI aims to measure the UE EE and represents the efficiency with which each Joule of energy is used to transmit information. This KPI expression represents the data volume (MBs of data transfer) of the UE under consideration, divided by the total energy consumed.		
2	*Methodology* For the evaluation, a full 5G deployment composed of a 5G UE, a 5G NR gNB and 5G core is used. A traffic generator capable of producing FTP traffic is used behind the N6 interface of 5G system and a traffic sink that collects traffic is used at the UE side.		
3	*Calculation process and output* **EC Measurement** The UE EC (EC_{UE}) is the refers to the EC of the US under investigation. The UE EC is measured using power meters or a Keysight N6705 power analyser to collect energy measurements from UE where a phone is powered directly through the Power Analyzer, rather than through its internal battery, which is disconnected. EC_{UE} is measured in Watts/hr.[13] (Wh = Joule), over the period of measurement T. **DV Measurement** The DV_{UE} shall be measured using network counters for data volume related to the aggregated traffic in the UE under test. DV_{UE} can be derived based on standard counters defined in ETSI TS 132 425 [18] for LTE (or 3GPP equivalent: TS 32.425), multiplying by the measurement duration T. DV_{UE} is computed in unit of bit. **OUTPUTs:** i)The $KPI_{UE\text{-}EE}$ (EE_{UE}), expressed unit of “bits/Joule” [equivalent to bits/Watt hour (Wh)]., is calculated as the ratio between the DV (DV_{UE}) and the EC (EC_{UE}), during the 7-day measurement period: $EE_{UE} = DV_{UE} / EC_{UE}$ (1) i)The **mean** (of the observed) values of EE_{UE} will be reported. The required results should be calculated according to the following methodology: Let EEavg_i be the calculated average EE for the ith iteration, and x_(i,n) be the measured EE for each iteration: $EEavg_i = \frac{1}{n}\sum_n x_{i,n}$ Then, the overall (reported) average EE*mean* shall be calculated as the average of all x_i		

13 1 Wh = 3·6 KJ

	$$EEmean = \frac{1}{i}\sum_{i} EEavg_i$$ For the overall average EE (EEmean), the 95% confidence interval shall be reported using the Student-T-distribution for *v = i - 1* degrees of freedom to denote the precision of the experiment.
4	*Complementary measurements* *The following complementary metrics will be available & logged during the measurement period:* *At the UE:* • *RSRP* • *RSRQ* • *SINR* *At the eNB/gNB:* • *Uplink Signal Strength* • *CQI reported from UE*
5	*Pre-conditions* The experimenter will define the following parameters of their setup: • Technology/Band • Transmission Mode (TDD/FDD) • Receive/Transmit Frequencies • Number of Antennas • Channel Bandwidth • UE Category • Service/slice configuration (eMBB, URLLC etc.) Prior to the beginning of the tests: • The UEs will be placed in various locations within the cell, including locations at the edge of the area (lowest SNR). • There will be only one or more UEs successfully connected to the network.
6	*Applicability* The UE and eNB/gNB should provide monitoring of the Complementary metrics.
7	*Test Case Sequence* 1. Place UEs (operating in NSA mode) in a test location corresponding to good coverage. 2. Configure the UE to download a test file size = 2 MB. 3. Start recording the complementary metrics. 4. Initiate the traffic generator in the Downlink with FTP traffic. 5. After the download is complete, allow the UE to go to inactive mode 6. Repeat step 13 to 15 i.e. repeat the procedure 20 times. 7. Stop recording the complementary metrics. 8. Upon completing the measurement, record the DV_{UE}.

	9. Upon completing the measurement, record the EC_{UE}. 10. After measuring the total energy consumed and computing the average per MB of data transfer, apply eq. (1). *11.* Report UE EE assessment results for 4G and 5G deployments separately, using the KPIs definition provided in section "*Calculation process and output*" as well as the templates provided in Section 4,5 and 6 of this document.

3.3.4 NB-IoT Device Energy Consumption

Test Case		TC_ENE_NBIoT_SUR	*Energy Efficiency*
1	*Target KPI* **NB-IoT Device Energy Consumption** The Average NB-IoT Device Energy Consumption test aims to evaluate the energy consumed by an NB-IoT device during a 10-year period of operation when uplink transfers are carried out with a particular periodicity and in message bursts of particular lengths. It is conducted in an OMNeT++ simulation environment with a purpose-built simulation model of the key parts of the NB-IoT network architecture.		
2	*Methodology* The NB-IoT Device Energy Consumption is measured at the simulation model of the NB-IoT device and is continually computed during a test run. Unless otherwise specified, the following power consumption values are used in the simulation:		

Activity	Power Consumption (mW)
Transmit	545
Receive	90
RRC Idle State (light sleep)	3
PSM mode (deep sleep)	0.015

The test comprises 30 iterations, and an iteration comprises the uplink transfer of traffic during a simulated 10-year period of operation, with a pre-specified periodicity between message transmissions and with a pre-specified message burst length.

3

Parameters

The following parameter settings are used in the test case:

Parameter	Value
Connected mode DRX (C-DRX)	disabled, 1.28 s, 2.56 s
Idle mode DRX (I-DRX)	1.28 s, 2.56 s
Paging Time Window (PTW) length	2.56 s
Inactivity timer	1 ms, 10 s, 20 s
Active timer (T_{3324})	18 s, 30 s, 60 s

	<table><tr><td>CoAP retransmission timer</td><td>2 s, 4 s, 8 s</td></tr></table>
4	*Calculation process and output* The average NB-IoT Device Energy Consumption in a test is calculated, according to the 5GENESIS Statistical Processing Methodology.
5	*Complementary measurements* None.
6	*Pre-conditions* • The OMNET++ simulation environment has been setup. • The simulation environment has been configured as specified in #3.
7	*Applicability* N/A
8	*Test Case Sequence* 1. Start the simulation of a particular test, i.e., a particular configuration of the simulation model and for uplink transfers that occur with a particular periodicity and with messages being transmitted in bursts of a particular length. 2. Run post-processing test scripts to extract the $Device\_EC_i$ 3. Repeat steps 1 and 2 for each iteration. 4. Calculate the $avgDevice\_EC$ and and its 95% CI.

3.4 Latency

3.4.1 E2E Application Layer Latency

Test Case		TC_LAT_e2eAppLayerLatency	Latency
1	*Target KPI* E2E Application Layer Latency This test aims at measuring the mean between a total of time of delays between the transmission and the reception of a data packet at application level, from a source and to the destination, and its processing. This latency is measured between a transmitter source and a receiver, in one direction each time, upstream or downstream. It is measured at the application layer. This test employs real application-oriented data packet to measure the latency metric within a real environment. Thus, the traffic profile of this test case is application dependent, and has different payload size and headers, thus, must be specified in the instantiation of the test case. Experimenters should include as part of their test case description an illustration of the measurement system, including if applicable and potential virtualization aspects. Source of packets →application acting as client Destination of packets → application acting as server Underlying SUT → Any deployed infrastructure of the specific platform, with the components related to a particular use case. Measurement conducted at layer → Application layer		
2	*Methodology* For measuring E2E Application Layer Latency, a packet is emitted from a source and received by the application. The times of emitting the packet at the data source and receiving the data packet at the data sink are to be captured and the Latency is calculated as the difference between the two events. For this test case, the traffic profile is application-based so, the data packet size and headers depending on the application used by the scenario. Moreover, the times for sending and receiving the packet are measured at the application level. Thus, this latency includes the de-encapsulation of the data within the packet from the receiver. The traffic source sends an Application data packet towards the destinations. The time between sending this packet at the sender and the time at which the destination receives the packet is captured. The clocks used for creating the two timestamps have to be previously well synchronized, preferably with an external source of time, and through the desired mechanism (GPS, PTP, NTP, etc.) The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → at least 1 minute, or the delivery of 50 packets. • A number of replica (iterations) → At least 25.		

3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* Other interesting measurements to be computed with the test results could be: • PLRate $$PLR = \frac{Num.of\ lost\ packets}{Num.of\ packets\ received + Num.of\ lost\ packets}$$ • Average E2E Latency per iteration
5	*Pre-conditions* Prior to the beginning of the tests: • All components belonging to the Use Case Application must be in place, running and connecting to each other. Thus, the source must reach the destination within a given time. Moreover, in the case of network slicing, the slice must be activated. • The source must generate the specified Application packet in a period interval. This data must arrive at least once to the destination, and the information within this data packet must arrive uncorrupted. • Ensure that unless specifically requested in the scenario, no undesired traffic is present during the test.
6	*Applicability* • The SUT must support/handle specific application type traffic. • The measurement probes need to be capable of injecting Application traffic in the system, or to be able to measure the traffic already exchanged by the SUT.
7	*Test Case Sequence* 1. Start the monitoring module to record the departure and arrival of the packets. 2. Log the information in a structured manner, this information includes timestamps, data information and other extra information that could be relevant for the probes. 3. Stop the monitoring module. 4. Calculate and record the average latency and the other parameters specified in this test case. 5. Replicate steps 1 to 5 the number of times specified in this test case. 6. Compute the total of KPI values defined in this test case.

3.4.2 Physical Layer Latency

	Test Case	TC_LAT_PHYLatency_MAL	Latency
1	*Target KPI* **PHY Layer Latency** This test aims at measure the mean between a total of time of delays between the transmission and the reception of a data packet at the PHY layer from a source and to the destination, representing a measurement of the radio interface latency. This latency is measured between a transmitter source and a receiver, in one direction each time, upstream or downstream. It is measured at the PHY layer, so the SUT must allow to measure at a point where packets haven't reached MAC layer yet. This test employs real application-oriented data packet to measure the latency metric within a real environment. Thus, the traffic profile of this test case is application dependent, and has different payload size and headers, thus, must be specified in the instantiation of the test case. Experimenters should include as part of their test case description an illustration of the measurement system. Source of packets →application acting as client Destination of packets → application acting as server Underlying SUT → The deployed infrastructure of the specific platform, with the components related to a particular use case. Measurement conducted at layer → PHY layer		
2	*Methodology* For measuring PHY Layer Latency, a packet is emitted from a source and received by an application. The times of emitting the packet at the data source after the MAC layer delivers it, and receiving the data packet at the data sink at MAC layer before its processing, are to be captured and the Latency is calculated as the difference between the two events. For this test case, the traffic profile is application-based so, the data packet size and headers depending on the application used by the scenario. Since the times for sending and receiving the packet are measured at the PHY level, it does not include the processing that takes place at MAC layer for neither source nor destination. The traffic source sends an Application data packet towards the destination. The time between sending this packet at the sender and the time at which the destination receives the packet is captured. The clocks used for creating the two timestamps have to be previously well synchronized, preferably with an external source of time, and through the desired mechanism (GPS, PTP, NTP, etc.) Using different network interfaces of a same machine assures a common clock and avoids the need of synchronization. Additionally, to make the test accurate to strictly measure the PHY layer delay, the test must be repeated without the SUT between data source and destination. This delay measurement must be subtracted from the measurement with the SUT to subtract the network interface in the PC from the measured system.		

	The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → at least 1 minute, or the delivery of 50 packets. • A number of replica (iterations) → At least 25.
3	*Calculation process and output* The required results should be calculated according to the following methodology: **Mean (average) PHY Layer Latency**: Let avg_i be the calculated average Latency for the i^th iteration, and x_(i,n) be the measured Latency for each packet, with a specific Application traffic profile, within the iteration. And avgNOSUT_i the calculated average Latency for the i^th iteration, and y_(i,n) be the measured Latency for each packet, without the SUT and a specific Application traffic profile, within the iteration $$avg_i = \frac{1}{n}\sum_n x_{i,n}$$ $$avgNOSUT_i = \frac{1}{n}\sum_n y_{i,n}$$ Then, the overall (reported) average Latency *avg* shall be calculated as the average of all x_i $$avg = \frac{1}{i}\sum_i avg_i - avgNOSUT_i$$
4	*Complementary measurements* Other interesting measurements to be computed with the test results could be: • PLRate $$PLR = \frac{Num.of\ lost\ packets}{Num.of\ packets\ received + Num.of\ lost\ packets}$$ • Average Latency per iteration
5	*Pre-conditions* Prior to the beginning of the tests: • All components must be in place, running and connecting to each other. Thus, the source must reach the destination within a given time. Moreover, in the case of network slicing the slice must be activated. • The source must generate the specified Application packet in a period interval. This data must arrive at least once to the destination and the information within this data packet must arrive uncorrupted. • Ensure that unless specifically requested in the scenario, no undesired traffic is present during the test.
6	*Applicability*

	• The SUT must support measuring at the PHY layer. • The SUT must support/handle specific application type traffic. • The measurement probes need to be capable of injecting Application traffic in the system, or to be able to measure the traffic already exchanged by the SUT.
7	*Test Case Sequence* 1. Start the monitoring module to record the departure and arrival of the packets. 2. Log the information in a structured manner, this information includes timestamps, data information and other extra information that could be relevant for the probes. 3. Stop the monitoring module. 4. Calculate and record the average latency and the other parameters specified in this test case. 5. Replicate steps 1 to 4 the number of times specified in this test case. 6. Replicate steps 1 to 5 without the SUT in the setup. 7. Compute the total of KPI values defined in this test case.

3.4.3 E2E GOOSE Message Latency

<table>
<tr><td colspan="2">Test Case</td><td>TC_LAT_SmartGridControlMsgLatency_BER</td><td>Latency</td></tr>
<tr><td>1</td><td colspan="3"> Target KPI E2E GOOSE Message Latency The E2E GOOSE Message Latency test aims to evaluate the time it takes for a piece of information that is published by an IED until it is received by an IED subscriber. The latency is measured at the application layer. The test is conducted on an Open5GCore test platform and considers two types of 5G core deployments: a VM- and a container-based deployment. </td></tr>
<tr><td>2</td><td colspan="3"> Methodology The E2E GOOSE Message Latency is measured as the time that elapses from that a piece of information is transmitted on the publisher interface on the GOOSE emulation machine until it is received on the subscriber interface on the GOOSE emulation machine. The test comprises 30 iterations, and an iteration comprises the transmission of 1000 Ethernet frames, each with a GOOSE message of 172 bytes. In an iteration, the E2E Latency for each transmitted GOOSE message is measured. </td></tr>
<tr><td>3</td><td colspan="3"> Parameters The following parameter settings are used in the test case:
<table>
<tr><th>Parameter</th><th>Value</th></tr>
<tr><td>GOOSE message size</td><td>172 bytes</td></tr>
<tr><td>Number of Ethernet frames</td><td>1000/iteration</td></tr>
<tr><td>Number of iterations</td><td>30</td></tr>
<tr><td>VM-based deployment</td><td>Ubuntu 18.10, KVM version 2.5.0</td></tr>
<tr><td>Container-based deployment</td><td>Ubuntu 18.10, Docker version 17.12</td></tr>
</table></td></tr>
<tr><td>4</td><td colspan="3"> Calculation process and output The average E2E Latency shall be calculated according to the 5GENESIS Statistical Processing Methodology. </td></tr>
<tr><td>5</td><td colspan="3"> Complementary measurements In each iteration, the 5GCore Latency is also measured. The 5GCore Latency is measured as the time it takes from when a GOOSE message enters the eNodeB until it exits the packet gateway (INET-GW). For the SUT this means the time that elapses from that a GOOSE message reaches the entry port of the Open5GCore server until it reaches the exit port of the Open5GCore server. The average 5GCore Latency shall be calculated according to the 5GENESIS Statistical Processing Methodology. </td></tr>
</table>

6	*Pre-conditions* • The test environment has been setup. • The GOOSE emulation machine has been configured.
7	*Applicability* • The SUT must support tunnelling of GOOSE messages • The traffic emulator must be able to inject GOOSE messages into the system
8	*Test Case Sequence* 1. Start monitoring traffic with tshark at the publisher and subscriber interfaces of the GOOSE emulation machine. 2. Start monitoring traffic with tshark at the entry and exit ports of the Open5GCore server. 3. Start the IEC 61850-8-1 GOOSE emulation tool. 4. Once the GOOSE emulation tool has completed, stop monitoring traffic in the GOOSE emulation machine at the 5GCore server. 5. Calculate the $avgE2E\_Delay_i$ and the $avg5GCore\_Delay_i$. 6. Repeat steps 1 to 5 for each iteration. 7. Calculate the $avgE2E\_Delay$ and $avg5GCoreDelay$ and their 95% CIs.

3.5 Round-Trip-Time

3.5.1 E2E Round-Trip-Time

	Test Case	TC_RTT_e2e	Round-Trip-time
1	*Target KPI* ***E2E Round-Trip-Time*** This KPI refers to the RTT measured between two endpoints. It measures the duration from the transmission of the data packet to the successful reception at the node of an external server (destination), plus the response time back to the source. Source A → Endpoint A Destination B → Endpoint B Underlying system → Any network components between the source and destination.		
2	*Methodology* For measuring RTT, a packet stream is emitted from a source and received by a data sink (destination). The data sink shall acknowledge the correct reception of the data packet back to the sink. The time of emitting the packet at the data source and receiving the acknowledgement at the data source are to be captured and the RTT is calculated as the difference between the two events. For this test case, the traffic source sends ICMP ECHO_REQUEST towards the destination, the latter responding with an ICMP ECHO_RESPONSE. This test case employs "ping" as a tool to generate the traffic stream. The default stream of generated ICMP ECHO_REQUESTs shall comply to the traffic profile specified in TP_ICMP_64. Additional traffic profiles may be applied for additional experiments. The experimenter shall state the traffic profile used in the experiment. The test case shall include the consecutive execution of several replica (iterations) according to the following properties. • Duration of a single replica (iteration) → at least 2 minutes ○ Note, the duration has to ensure that at least 100 ICMP ECHO_REQUESTs are sent during a single replica (iteration). • Number of replica (iterations) → At least 25		
3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		
4	*Complementary measurements* • Ping Success Rate • PL Rate • Average RSRP (if available)		

	• Average RSRQ (if available) The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
5	*Pre-conditions* The scenario has been configured. In case of network slicing, the slice must be activated. The traffic generator should support the generation of the traffic pattern defined in the traffic profiles section. Connect the traffic generator to the endpoints if they do not include one. Deploy the monitoring probes to collect the primary and complementary metrics. Ensure that unless specifically requested in the scenario, no undesired traffic is present during the test.
6	*Applicability* For networks and devices that support internal traffic generation or routing external IP traffic
7	*Test Case Sequence* 1. Trigger the monitoring probes to collect the primary and complementary metrics, if applicable. 2. Triger the traffic generator from the source to the destination using one of the ICMP traffic profiles defined. 3. Record RTT, number of packets “ICMP request” sent and number of packets “ICMP reply” received. 4. Stop monitoring probes 5. Record the average RTT, the average PL rate and the average ping success rate, the average RSRP and the average RSRQ per iteration as defined in “Calculation process and output”. 6. Repeat steps 1 to 5 for each one of the 25 iterations 7. Compute the KPIs as defined in section “Calculation process and output”.

3.5.2 E2E Round-Trip-Time with background traffic

Test Case		TC_RTT_e2eBGTraffic	*Round-Trip-time*
1	*Target KPI* ***E2E Round-Trip-Time with background traffic*** This KPI refers to the RTT measured between two endpoints under concurrent network load. It measures the duration from the transmission of the data packet to the successful reception at the node of an external server (destination) plus the response time back to the source. Source → Endpoint A Destination → Endpoint B Underlying system → Any network components between the source and destination		
2	*Methodology* For this test case, the traffic source sends ICMP ECHO_REQUEST towards the destination, the latter responding with an ICMP ECHO_RESPONSE. This test case employs “ping” as a tool to generate the traffic stream. In parallel, a traffic generator is employed to produce background traffic. The experimenter shall describe the traffic profile of the background traffic used in the experiments. The default stream of generated ICMP ECHO_REQUESTs shall comply to TP_ICMP_64 traffic profile. Additional traffic profiles may be applied for additional experiments. The experimenter shall clearly define the traffic profile used. The test case shall include the consecutive execution of several replica (iterations) according to the following properties: • Duration of a single replica (iteration) → at least 2 minutes o Note, the duration must ensure that at least 100 ICMP ECHO_REQUESTs are sent during a single replica (iteration). • Number of replica (iterations) → At least 25		
3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Methodology.		
4	*Complementary measurements* • Ping Success Rate • PL Rate • Average RSRP (if available) • Average RSRQ (if available) • Average IP throughput of background traffic during the test The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		
5	*Pre-conditions* The network is operational. The traffic generator supports the traffic profiles.		

	If the endpoints do not include a traffic generator, connect an external server to accommodate the generator. The monitoring probes are able to record the complementary metrics. Ensure that unless specifically requested in the scenario, no undesired traffic is present during the test.
6	*Applicability* N/A
7	*Test Case Sequence* 1. Trigger the monitoring probes to collect the complementary metrics. 2. Define the traffic profile of the background traffic. Trigger the traffic generator to transmit background traffic. 3. Initiate ping requests from the source to the destination using one of the ICMP traffic patterns defined. 4. Record RTT, number of transmitted and received packets. 5. Stop the monitoring probes 6. Calculate and record the average RTT, the average PL rate and the average ping success rate, the average RSRP, the average RSRQ and the average IP throughput per iteration as defined in "Calculation process and output". 7. Repeat steps 1 to 5 for each one of the 25 iterations 8. Compute the KPIs as defined in section "Calculation process and output".

3.5.3 E2E Round-Trip-Time and Radio Link Quality

Test Case		TC_RTT_e2eRadioLinkQuality	*Round-Trip-time*
1	*Target KPI* ***E2E Round-Trip-Time with background traffic*** This KPI refers to the RTT measured between two endpoints in three different cell locations (edge, mid-cell, peak conditions). It measures the duration from the transmission of the data packet to the successful reception at the node of an external server (destination) plus the response time back to the source and evaluates the impact of Radio Link Quality. Source → Endpoint A Destination → Endpoint B Underlying system → Any network components between the source and destination		
2	*Methodology* For this test case, the traffic source sends ICMP ECHO_REQUEST towards the destination, the latter responding with an ICMP ECHO_RESPONSE. This test case employs "ping" as a tool to generate the traffic stream. The stream of generated ICMP ECHO_REQUESTs shall comply to the traffic profile specified in TP_ICMP_64. Additional traffic profiles may be applied for additional experiments. The experimenter shall state the traffic profile used. The test case shall include the consecutive execution of several replica (iterations) in each cell location (peak conditions, mid-edge, cell-edge), according to the following properties: • Duration of a single replica (iteration) → at least 2 minutes ○ Note, the duration has to ensure that at least 100 ICMP ECHO_REQUESTs are sent during a single replica (iteration). • Number of replica (iterations) → At least 25 the experimenter shall conduct the above measurements in three different cell locations (edge, mid-cell, peak conditions)		
3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Methodology.		
4	*Complementary measurements* • Ping Success Rate • PL Rate • Average RSRP (Reference Signal Received Power) if available • Average RSRQ (Reference Signal Received Quality) if available • Average IP throughput of background traffic during the test The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		

5	*Pre-conditions* The network is operational. The traffic generator supports the traffic profiles. If the endpoints do not include a traffic generator, connect an external server to accommodate the generator. The monitoring probes are able to record the complementary metrics.
6	*Applicability* For networks and devices that support internal traffic generation or routing external IP traffic
7	*Test Case Sequence* 1. Select a cell location with peak conditions. 2. Trigger the monitoring probes to collect the complementary metrics. 3. Define the traffic profile of the background traffic. Trigger the traffic generator to transmit background traffic. 4. Initiate ping requests from the source to the destination using one of the ICMP traffic patterns defined. 5. Record RTT, number of transmitted and received packets. 6. Stop the monitoring probes. 7. Repeat steps 1 to 6 for each one of the 25 iterations. 8. Calculate and record the average RTT, the average PL rate and the average ping success rate, the average RSRP, the average RSRQ and the average IP throughput per iteration as defined in “Calculation process and output”. 9. Compute the KPIs as defined in section “Calculation process and output”. 10. Repeat Steps 1-9 for mid-edge and cell-edge cell locations.

3.6 Delay

Delay tests were not conducted during the 5GENESIS experimentation Phases 1 & 2. Corresponding test cases will be added in a later revision of this Companion Document.

3.7 Location Accuracy

Delay tests were not conducted during the 5GENESIS experimentation Phases 1 & 2. Corresponding test cases will be added in a later revision of this Companion Document.

3.8 Reliability

Delay tests were not conducted during the 5GENESIS experimentation Phases 1 & 2. Corresponding test cases will be added in a later revision of this Companion Document.

3.9 Service Creation Time

3.9.1 Service Creation Time for deploying virtual instruments on a single compute host

<table>
<tr><th colspan="2">Test Case</th><th>TC_SCT_VMDeploymen_BER</th><th>Service Creation Time</th></tr>
<tr><td>1</td><td colspan="3"> Target KPI Service Creation Time
for deploying virtual instruments on a single compute host This KPI refers to the time needed to deploy a single virtual machine (VM), which may act as virtual instruments, on a single compute machine. The main intend is to evaluate the capability of the system to deploy a service (VNFs) on an existing, i.e. previously deployed, 4G/5G Network. Since the test case mandates that both VMs are deployed on the same compute host, i.e. in a single availability zone, potential effects of deploying VNFs in different zones do not impact the results. For this test, a simple VM is deployed. To assure correct deployment of a service offered by the VM, a “ping” is triggered from that machine towards a remote host. The latter step not being part of the time measured. As such, the deployed VNF offers the service “reachability test”. Source A → Virtual Machine / VNF deployed Destination B → Remote server in the testbed or outside the testbed Underlying system → OpenStack Layer → Network layer </td></tr>
</table>

2	*Methodology* For measuring the service creation time, the deployment of a single VM (Debian-9-based) is triggered by the orchestrator of the testbed. The time between triggering the deployment process and the indication of a successful deployment is measured. After the deployment, the VM is used to conduct a “ping” (offered service) originating at the deployed VM towards any reachable remote host. Since the duration of this service test is not part of the measurement, the specification on how to parameterize the “ping” is out of scope of this test case. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → deployment of the single VNF / VM • Number of iterations → At least 25 iterations
3	*Calculation process and output* The average Service Creation Time shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* Deployment Success Rate in % (number of deployments, which resulted in a successful ping afterwards).
5	*Pre-conditions* A deployed and working OpenStack facilitating the deployment of VNFs / VMs via an orchestrator (e.g. OpenBaton or OSM). An existing remote server that can be used to conduct the service test, i.e. to ping. No other VMs / VNFs are deployed on the compute hosted on which the single VNF / VM for this test case is deployed.
6	*Applicability* This test case applies for all scenarios as it assumes an underlying network infrastructure to deploy the VNFs/VMs in.
7	*Test Case Sequence* 1. Trigger the deployment of the VNF/VM from the orchestrator, or from experiment coordinator (TAP) on top of the latter. 2. Wait for a response indicating successful deployment 3. Calculate the deployment time (time between steps 1 and 2) 4. Verify that the deployed service is working, i.e. ping the remote machine from the deployed VM; and record if this test is successful or fails. Note: a test case defined for the e2e RTT may be used for this. In that case, only 1 iteration and 1 replica is needed as the actual RTT value is not recorded.

	5. Delete VNF (In other to have the same conditions in each iteration the VNF deployed should be removed) 6. Repeat steps 1 to 5 for each one of the 25 iterations 7. Compute the KPIs as defined in section “Calculation process and output”.

3.9.2 Service Creation Time of 5G end-to-end connectivity service

Test Case		TC_SCT_5GConnSliceInstantiation	Service Creation Time
1	*Target KPI* ***Service Creation Time of 5G end-to-end connectivity service*** This Service Creation Time test aims to assess the duration of an 5G end-to-end connectivity service instantiation. For this test, the service instantiation process includes the creation of a network slice that contains a vEPC (Core Network instance) deployment, inside a virtualized infrastructure followed by the proper configuration to achieve mobile network connection in a “sliced” environment. The final “Service Creation Time” KPI metrics are collected. The time between triggering the deployment process and the indication of a successful configuration is measured. Measurement conducted at layer → Application layer		
2	*Methodology* For measuring the service creation time, the creation of a Network Slice and the deployment of a vEPC instance is triggered by the experimenter through the orchestrator of the testbed. After the deployment phase, all network elements (WAN, Radio) are configured by the Network Management System (NMS) to provide the 5G connectivity service and provide users with internet connectivity. The Slice Manager records timestamps to measure the duration of the slice deployment process. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → An instantiation of a Slice Network Service • Number of iterations → 25 iterations of connectivity service instantiation		
3	*Calculation process and output* The average Service Creation Time shall be calculated according to the 5GENESIS Statistical Processing Methodology.		
4	*Complementary measurements* Deployment Success Rate in % (number of deployments, which resulted in a successful ping afterwards).		

5	*Pre-conditions* • A deployed and working VIM (e.g. Openstack) facilitating the deployment of VNFs / VMs via an NFVO (e.g. OpenBaton or OSM). • Deployed and working open5Genesis platform components (Portal, ELCM, Slice Manager, NMS)
6	*Applicability* This test case applies to the measurement of Service Creation Time KPI during the instantiation of 5G end-to-end connectivity service running on top of a network slice.
7	*Test Case Sequence* 1. Create an experiment through the Portal to run the Service Creation Time Test Case and upload the Network Slice Template (NST) that specifies the network slice requirements and SLAs. Trigger the experiment. 2. The Slice Manager receives the request from the ELCM to instantiate the 5G end-to-end connectivity service. 3. A slice containing the vEPC instance is created inside the virtual infrastructure. 4. Network elements configuration is done by the NMS and service becomes operational 5. The slice manager provides the results to the ELCM. 6. Repeat steps 2 to 5 for each one of the 25 iterations 7. Compute the KPIs as defined in section “Calculation process and output”.

3.10 Speed

Delay tests were not conducted during the 5GENESIS experimentation Phases 1 & 2. Corresponding test cases will be added in a later revision of this Companion Document.

3.11 Throughput

3.11.1 TCP Throughput

Test Case		TC_THR_Tcp	Throughput
1	*Target KPI* ***TCP Throughput*** The Throughput calibration test aims to assess the measurement capabilities of the measurement system employed in future Throughput tests. Measurement probes may be virtualized or physical. In case of virtualized probes, all probes shall be instantiated on the same (physical) host. In case of physical probes, the latter shall be preferably directly connected. Source of packets → measurement probe acting as traffic generator Destination of packets → measurement probe acting as recipient Underlying SUT → Network components (if applicable) between the source and the destination Measurement conducted at layer → Application layer		
2	*Methodology* For measuring Throughput, a packet stream is emitted from a source and received by a data sink (destination). The amount of data (Byte) successfully transmitted per unit of time (seconds) as measured by the traffic generator and the probes shall be recorded. A TCP-based traffic stream is created between the source and the destination using the iPerf3 tool. [iPerf.fr]; to reduce impacts of TCP slow-start algorithm, the first 20 s of a measurement are discarded. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → at least three (3) minutes, where the first 20 seconds of measurements are discarded. • Records throughput over 5-second intervals within an iteration. • Number of replica → At least 25 iterations.		
3	*Parameters* The test case shall include the consecutive execution of several replica (iterations) according to the following parameters:		

	Parameter	iPerf3 Option	Suggested Value
	Throughput measurement interval	--interval	5
	Number of simultaneously transmitting probes/ processes/ threads	--parallel	1
	Bandwidth limitation set to unlimited	n/a	Unlimited is the default for iPerf for TCP
	Omit first n seconds of the test to skip TCP slowstart	--omit	20
	Iteration duration	--time	180
	Number of iterations	n/a	At least 25
	Format to report iPferf results in (report in Mbits/sec)	--format	m

3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Complementary measurements* • PL Rate The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
5	*Pre-conditions* • The scenario has been configured. • The traffic generator should support the generation of the traffic pattern defined in the Throughput traffic patterns section. • Ensure that no undesired traffic is present during the test.
6	*Applicability* The measurement probes need to be capable of injecting traffic into the system and assessing successful or unsuccessful transmission of the data, as well as determining the throughput of the transmission.
7	*Test Case Sequence* 1. Start monitoring probes (deployment of probes running iPerf client and server). 2. Using the traffic generator, begin transmitting from the client probe to the server probe, as defined in Section “Parameters”. 3. Record the Throughput for each time interval within a trial. 4. Stop the traffic generator. 5. Stop monitoring probes 6. Calculate and record the KPIs as needed per iteration as defined in “Calculation process and output”.

	7. Repeat steps 1 to 6 for each one of the 25 iterations 8. Compute the KPIs as defined in section "Calculation process and output"

3.11.2 UDP Throughput

Test Case		TC_THR_Udp	Throughput
1	*Target KPI* **UDP Throughput** The UDP Throughput test aims at assessing the maximum throughput of a network system. Measurement probes may be virtualized or physical. In case of virtualized probes, all probes shall be instantiated on the same (physical) host. In case of physical probes, the latter shall be preferably directly connected. Source of packets → measurement probe acting as traffic generator. Destination of packets → measurement probe acting as recipient. Underlying SUT → Network components between the source and destination. Measurement conducted at layer → Application layer.		
2	*Methodology* For measuring Throughput, a packet stream is emitted from a source and received by a data sink (destination). The amount of data (Byte) successfully transmitted per unit of time (seconds) as measured by the traffic generator and the probes shall be recorded. For consistency among calibration tests, a UDP-based traffic stream is created between the source and the destination using the iPerf2 tool. [iPerf.fr] The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → at least three (3) minutes. • Records throughput over 5-second intervals within an iteration. • Number of replicas → At least 25 iterations.		
3	*Parameters* The test case shall include the consecutive execution of several replica (iterations) according to the following parameters.		

Parameter	iPerf Option	Suggested Value
Throughput measurement interval	--interval	5
Number of simultaneously transmitting probes/ processes/ threads	--parallel	4 (in order to reach higher data rate)

	Bandwidth limitation set to above the maximum bandwidth available	--b	Depends on the maximum theoretical throughput available in the network
	Iteration duration	--time	180
	Number of iterations	n/a	At least 25
	Format to report iPferf results in (report in Mbits/sec)	--format	m
4	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		
5	*Complementary measurements* Note: PL rate is not recorded because constant traffic in excess of the available capacity will be used and the excess will be discarded, as expected.		
6	*Pre-conditions* • The scenario has been configured. • The traffic generator should support the generation of the traffic pattern defined in the "Parameters" Section. • Ensure that no undesired traffic is present during the test.		
7	*Applicability* The measurement probes need to be capable of injecting traffic into the system as well as determining the throughput of the transmission.		
8	*Test Case Sequence* 1. Start monitoring probes (deployment of probes running iPerf client and server). 2. Using the traffic generator, begin transmitting from the client probe to the server probe, as described in *Section* "Parameters". 3. Record the Throughput for each time interval within a trial. 4. Stop the traffic generator. 5. Stop monitoring probes 6. Calculate and record the KPIs as needed per iteration as defined in "Calculation process and output". 7. Repeat steps 1 to 6 for each one of the 25 iterations 8. Compute the KPIs as defined in section "Calculation process and output".		

3.12 Ubiquity/Coverage

Note: Ubiquity and Coverage are terms that are used interchangeably.

3.12.1 RAN Coverage

Test Case		*TC_UBI_RANCoverage*	*RAN Coverage*
1	*Target KPI* ***Ubiquity/Coverage***		
2	*Methodology* While coverage measurements, in a degree, depend on the specific service/application to be considered, for the tests in 5GENESIS we will use a simple approach involving ICMP ECHO messages to verify basic data connectivity. ICMP ECHO messages are exchanged on E2E basis between a couple of measurement probes (virtual or physical) installed at i) the UE and ii) behind the core network (EPC/5GC) respectively. In any case, the probe at the UE will issue an ICMP ECHO request and the probe at the core will reply with an ICMP ECHO reply. 1400-byte packets will be used, according to TD_ICMP_1408. One iteration consists of 100 consecutive requests, sent at a rate of 2 requests/sec. ICMP PL will be measured at the request issuer (UE). Measurements are taken into various UE locations (see later "Test case sequence").		
3	*Calculation process and output* We consider n measurements at n different locations (see below "Test case sequence"). For each location i, we perform a measurement iteration and we assume: $x_i = 0$ if the location is considered out of coverage, i.e. ICMP PL is above a specified threshold (we assume 5%) $x_i = 1$ if the location is considered in coverage, i.e. ICMP PL is below a specified threshold (we assume 5%). Then the coverage KPI (as percentage) is calculated as $$C = \frac{1}{n}\sum_{n} x_i \cdot 100\%$$		
4	*Complementary measurements* Along with PL, ICMP RTT (average, min, max and standard deviation) will be recorded. Also, RSSI and RSRQ will be measured, both at the UE and the eNB/gNB.		
5	*Pre-conditions* The following pre-conditions should apply prior to the beginning of the tests:		

	• The network shall operate properly. • The network will serve no other user traffic (verified in eNB/gNB monitoring) • A single UE will be connected Exact RAN parameters and configuration (antenna gain, band, bandwidth, other PHY configuration parameters) etc. will depend on the actual setup/scenario, yet they should be consistent across all tests for the specific scenario.
6	*Applicability* N/A
7	*Test Case Sequence* 1. Divide the area under consideration into a grid of equally spaced locations 2. With the gNB/eNB fixed, move the UE in location i 3. Perform a measurement iteration. 4. The location is considered out of coverage, i.e. ICMP PL is above a specified threshold (we assume 5%), it is considered in coverage otherwise. 5. Repeat steps (2-4) for all locations in the area 6. Calculate coverage as defined above ("Calculation process").

3.12.2 Backhaul Coverage

Test Case		TC_UBI_BHCoverage	Backhaul coverage
1	*Target KPI* ***Ubiquity/Coverage*** The backhaul coverage test addresses cases where a wide-area wireless backhaul network is used to support a mobile 5G access network ("hotspot").		
2	*Methodology* While coverage measurements, in a degree, depend on the specific service/application to be considered, for the tests in 5GENESIS we will use a simple approach involving ICMP ECHO messages to verify basic data connectivity. ICMP ECHO messages are exchanged on E2E basis between a couple of measurement probes (virtual or physical) installed at i) the UE and ii) behind the core network (EPC/5GC) respectively. In any case, the probe at the UE will issue an ICMP ECHO request and the probe at the core will reply with an ICMP ECHO reply. 1400-byte packets will be used, according to TD_ICMP_1408. One iteration consists of 100 consecutive requests, sent at a rate of 2 requests/sec. ICMP PL will be measured at the request issuer (UE). In the backhaul coverage test, we consider the UE to be co-located with the (mobile) eNB/gNB in order to secure RAN coverage and to exclude outages which may be due to poor RAN signal. We assume the UE to be at a distance of max. 1m from the eNB/gNB, under LoS conditions. That is, the UE moves around together with the mobile 5G remote network (hotspot). Measurements are taken into various hotspot locations (see later "Test case sequence").		
3	*Calculation process and output* We consider n measurements at n different locations (see below "Test case sequence") of the remote 5G network (hotspot). For each location i, we perform a measurement iteration and we assume: $x_i = 0$ if the location is considered out of coverage, i.e. ICMP PL is above a specified threshold (we assume 5%). $x_i = 1$ if the location is considered in coverage, i.e. ICMP PL is below a specified threshold (we assume 5%). Then the backhaul coverage KPI (as percentage) is calculated as $$C = \frac{1}{n}\sum_{n} x_i \cdot 100\%$$		
4	*Complementary measurements* Along with packet loss, ICMP round trip time (average, min, max and standard deviation) will be recorded.		

	Also, RSSI and RSRQ (or equivalent values, depending on the wireless backhaul technology) will be measured, at both radio units of the wireless backhaul link.
5	*Pre-conditions* The following pre-conditions should apply prior to the beginning of the tests: • The network shall operate properly. • The network will serve no other user traffic (verified in eNB/gNB monitoring). • A single UE will be connected. • The UE will be stationary and at a distance of 1 m from the eNB/gNB antenna, at line-of-sight conditions (i.e. the RAN is considered stable). Exact backhaul parameters and configuration (antenna gain, band, bandwidth, other PHY configuration parameters) etc. will depend on the actual setup/scenario, yet they should be consistent across all tests for the specific scenario.
6	*Applicability* N/A
7	*Test Case Sequence* 1. Divide the area of the wireless backhaul network coverage under consideration into a grid of equally spaced locations. The backhaul radio node which is connected to the core network side is considered fixed. 2. Move the second backhaul radio node, along with the entire 5G hotspot and the UE, in location i. If necessary, re-align the backhaul network antennas. 3. Perform a measurement iteration. 4. The location is considered out of backhaul coverage, i.e. ICMP PL is above a specified threshold (we assume 5%), it is considered in coverage otherwise. 5. Repeat steps (2-4) for all locations in the area 6. Calculate backhaul coverage as defined above ("Calculation process").

3.12.3 NB-IoT RAN Coverage

Test Case		TC_UBI_NBIoTRAN	Ubiquity
1	*Target KPI* **NB-IoT RAN Coverage** The aim of this Test Case is to assess NB-IoT signal coverage and availability in heterogeneous scenarios (e.g., deep indoor, indoor, and outdoor). Hence, the Test Case comprises passive measurements of the level of signal strength and quality of the NB-IoT Reference Signal. The latter is transmitted in downlink by NB-IoT-enabled cellular eNBs and corresponding cells. The target KPI is the Narrowband Reference Signal Received Power (RSRP [dBm]). Complementary metrics are given in Section 4 of this Test Case.		
2	*Methodology* Once a scenario under test is chosen (e.g., deep indoor, indoor, or outdoor), a measurement site complying with this scenario must be selected (e.g., a (deep) indoor location or an outdoor path). In the selected measurement site, the following operations have to be executed: • Configure a spectrum scanner to i) perform frequency sweeps on cellular licenced spectrum portions, and ii) detect-and-decode NB-IoT signals in guard-band, in-band, or stand-alone operation modes. • Enable the scanner to collect samples for both target KPI and complementary metrics, for at least 5 minutes with no interruption. The above procedures identify a **measurement campaign** for the scenario under test. In order to provide reliable statistics for the scenario under test, the same measurement campaign has to be repeated either at the same site several times and/or at different sites complying with the scenario under test. At least 10 measurement campaigns are suggested.		
3	*Calculation process and output* Given a measurement campaign (as defined in Section 2 of this Test Case), the highest NB-IoT RSRP perceived among multiple eNBs (and corresponding cells) is extracted either for each frequency sweep (in case of a static campaign) or for each measurement location (in case of a mobile campaign). The average of the extracted values is evaluated and identifies the campaign average RSRP. The statistical indicators of the campaign average RSRP identify the Test Case outputs. In particular, Min, Max, Average, Median, 5% and 95% Percentiles are required for assessing the Test Case results. If the test is performed on operational networks, the above calculation has to be executed by differentiating eNBs and cells belonging to different operators' RAN infrastructures.		

4	*Complementary measurements* Besides NB-IoT RSRP, the collection of NB-IoT SINR and NB-IoT RSRQ is suggested for a complete assessment of NB-IoT coverage. These two measurements follow the same calculation process defined for the target KPI (see Section 3 of this Test Case) and are presented in the same way. If available, it is also suggested the parallel collection of the same parameters for the technology currently in use for eMBB services (e.g., LTE, LTE-A, or 5G NR). This enables the assessment of NB-IoT coverage enhancement with respect to eMBB technologies. Depending on the scenario under test, the measurement setup may include a Global Positioning System (GPS) antenna to keep track of the locations at which the measurements are performed (e.g., for stationary indoor tests the GPS may be avoided, while it is beneficial for mobile outdoor campaigns).
5	*Pre-conditions* ● The scenario under test is selected along with the measurement site(s). ● The scanner is configured and operative, enabling the collection of the target KPI and complementary metrics. ● If included in the measurement setup, the GPS is operative and enables location estimation and tracking.
6	*Applicability* The scanner must have the detecting-and-decoding capabilities for all possible NB-IoT operation modes (see Section 2 of this Test Case).
7	*Test Case Sequence* 1. Place the scanner in the selected measurement site (if the campaign is mobile, the scanner is carried around by a human surveyor while walking or driving). 2. Configure and activate the scanner for the collection of the metrics (at least 5 minutes). 3. Deactivate the scanner when the collection is terminated. 4. Repeat 1-3 for all the measurement sites complying with the scenario under test (at least 10). 5. Extract the collected metrics and perform the calculation process reported in Section 3 of this Test Case.

3.13 MCPTT

3.13.1 MCPTT Access Time without call establishment

Test Case		*TC_MCPTTAccessTime_MAL*	*MCPTT*
1	*Target KPI* ***MCPTT access time without Call Establishment*** The MCPTT access time is defined as the time between when an MCPTT User requests to speak and when this user gets a signal to start speaking. This time does not include confirmations from receiving users. Measurement probes may be virtualized or physical. In case of virtualized probes, all probes shall be instantiated on the same (physical) host. In case of physical probes, they shall, preferably, be directly connected. Experimenters should include as part of their test case description an illustration of the measurement system, including (if applicable) potential virtualization aspects. Source of floor control packets →measurement probe acting as client Destination of floor control packets → measurement probe acting as server Underlying SUT → Any network components between the probes Measurement conducted at layer → Application layer		
2	*Methodology* The measurement procedure only requires to have an ongoing call, and requesting and releasing the token. The request is logged when the MCPTT request event is created with the next message: KPI1_PERFORMANCE,TOKEN REQUEST,currentTime On the other hand, the granted state (in case the token is granted to the requested user after a token idle situation) is logged with the next message: KPI1_PERFORMANCE,TOKEN GRANTED,currentTime Using the logged timestamps, we can calculate the accurate time that MCPTT access takes. The test case shall include the consecutive execution of several replica (iterations) according to the following properties. • Duration of a single replica (iteration) → the duration has to ensure that at least 20 KPI1_PERFORMANCE,TOKEN REQUEST,currentTime are sent during a single replica (iteration), and that the same amount of KPI1_PERFORMANCE,TOKEN GRANTED,currentTime are responded. • Number of replica (iterations) → At least 25		
3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		

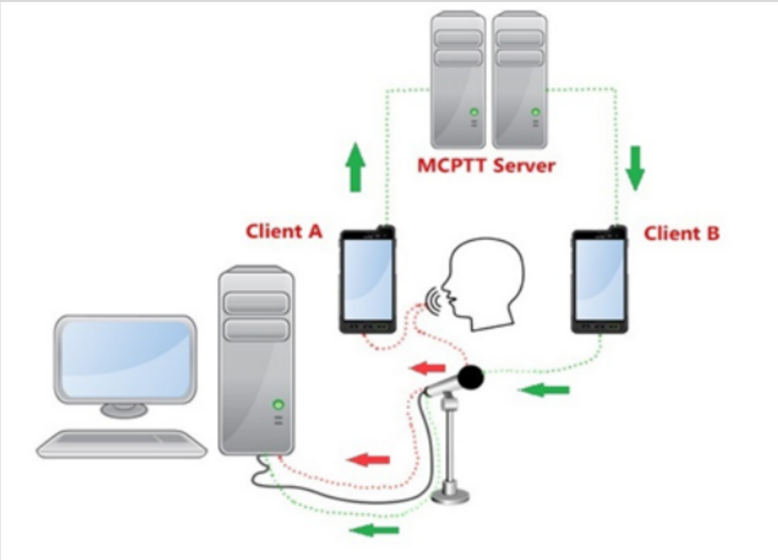
4	*Pre-conditions* In order to start the execution of this test, there must be an ongoing call.
5	*Applicability* Measurement of 3GPP standardized MCPTT access time delay KPI. This test case must be executed using MCPTT 3GPP compliant UEs.
6	*Test Case Sequence* 1. Start the MCPTT system. 2. Establish an MCPTT call. 3. Perform the token request, in order to generate the desired messages, which will be recorded. 4. Repeat the token or floor request and release procedure or finish the call. 5. Calculate and record the average MCPTT access time per iteration as defined in "Calculation process and output". 6. Repeat steps 1 to 5 for each one of the 25 iterations 7. Compute the KPIs as defined in section "Calculation process and output".

3.13.2 MCPTT E2E Access Time including call establishment

Test Case	*TC_MCPTTAccessTimeIncCallEstablishment_MAL*	*MCPTT*
1	*Target KPI* ***E2E MCPTT Access Time including Call Establishment*** According to the standard the E2E MCPTT Access time is defined as the time between when an MCPTT User requests to speak and when this user gets a signal to star speaking, including MCPTT call establishment and possibly acknowledgment from first receiving user before voice can be transmitted. Source of INVITE packet and destination of confirmation packet →measurement probe acting as client 1. Destination of INVITE packet and source of confirmation packet → measurement probe acting as client 2. Underlying SUT → Any network components between the probes. Measurement conducted at layer → Application layer.	
2	Methodology In order to get the accurate time of the E2E MCPTT Access time delay we log the function that sends the INVITE and the one which receives the 200 OK relative to that INVITE from the MCPTT/MCS system, after the confirmation by the callee.	

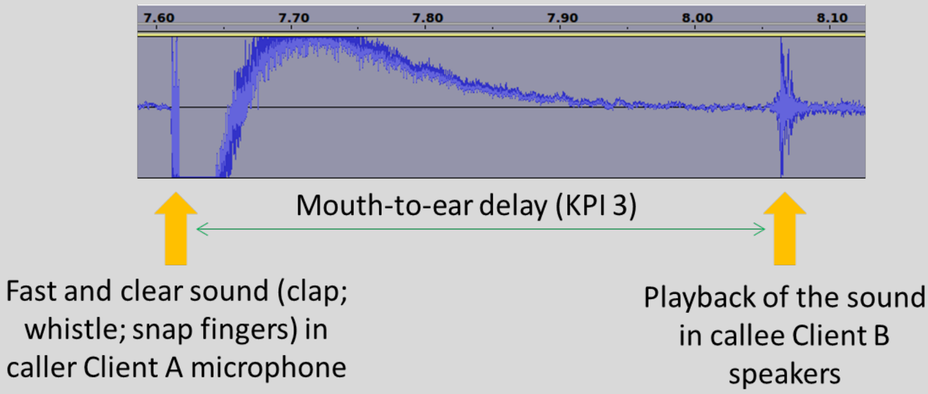
	To ensure that the 200 OK is the response to the sent INVITE by the caller we have logged the Command sequence (Cseq) field of the INVITE and 200 OK messages. For instance, in the following way: KPI2_PERFORMANCE,INVITE,currentTime,cseq KPI2_PERFORMANCE,200 OK,currentTime,cseq The test case shall include the consecutive execution of several replica (iterations) according to the following properties. • Duration of a single replica (iteration) → the duration has to ensure that at least 20 KPI2_PERFORMANCE,INVITE,currentTime,cseq are sent during a single replica (iteration), and that the same amount of KPI2_PERFORMANCE,200 OK,currentTime,cseq are responded. • Number of replica (iterations) → At least 25
3	*Calculation process and output* The required results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
4	*Pre-conditions* The service MCPTT/MCS VNFs should be instantiated, the whole set of services up and running, the UE connected to an actual RAT that is able to reach the deployed VNFs going through a core network.
5	*Applicability* Measurement of 3GPP standardized E2E MCPTT access time delay This test case must be executed using MCPTT 3GPP compliant UEs.
6	*Test Case Sequence* 1. Start the MCPTT system. 2. Establish an MCPTT call. 3. Finish the call. 4. Calculate and record the average E2E MCPTT access time per iteration as defined in “Calculation process and output”. 5. Repeat steps 1 to 3 for each one of the 25 iterations 6. Compute the KPIs as defined in section “Calculation process and output”

3.13.3 MCPTT Mouth-to-Ear Delay

	Test Case	TC_MCPTTMouthtoEarDelay	MCPTT
1	*Target KPI* ***MCPTT Mouth-to-Ear Delay*** The MCPTT mouth-to-ear delay is the time between an utterance by the transmitting user, and the playback of the utterance at the receiving user's speaker. Source of RTP packets →measurement probe acting as client A Destination of RTP packets → measurement probe acting as client B Underlying SUT → Any network components between the probes Measurement conducted at layer → Application layer		
2	*Methodology*  Client A and B are placed next to each other providing that there is sufficient space so as to ensure no audio coupling. Next to the devices, a microphone is placed in order to capture the complete sound activity. Attached to the microphone, there is a need for a computer running a sound recording tool (e.g. Audacity). Once defined the measurement setup, it is important to define the procedure in order to be capable of gathering significant samples. 1. Client A plays the role of caller and client B does the same as a callee. 2. Client A calls client B with implicit token request. 3. The call is established and client A has the token. Client B enables the speaker (up to the measurement configuration but helps capture the incoming sound). 4. Start recording in the audio recording tool. 5. Through the client A terminal, we make a clear and fast sound (e.g. clap, whistle, snap fingers). This sound is captures by the microphone and recorded by the audio recording tool in the computer.		

<table>
<tr><td></td><td>
6. The sound travels all the way until the client B. When the client B receives and plays the sound, the microphone captures it and the audio recording tool stores it, being able to measure the time-gap between the sound creation event and the reception event (MCPTT mouth-to-ear delay).

The next figure shows an example obtained with audacity while making a clear sound with a clap. Even though the audio recording tool also records echoes in the lab, it is clear that the delay is approximately 450ms (from slightly more than 7.6 s to slightly more than 8.05 s).



The test case shall include the consecutive execution of several replica (iterations) according to the following properties.

- Duration of a single replica (iteration) → the duration has to ensure that at least 20 messages of each required type are sent during a single replica (iteration).
- Number of replica (iterations) → At least 25.
</td></tr>
<tr><td>3</td><td>

Calculation process and output

The results shall be calculated according to the 5GENESIS Statistical Processing Methodology.
</td></tr>
<tr><td>4</td><td>

Pre-conditions

The service MCPTT/MCS VNFs should be instantiated, the whole set of services up and running, the UE connected to an actual RAT that is able to reach the deployed VNFs going through a core network.
</td></tr>
<tr><td>5</td><td>

Applicability

Measurement of 3GPP standardized MCPTT mouth-to-ear delay

This test case must be executed using MCPTT 3GPP compliant UEs.
</td></tr>
<tr><td>6</td><td>

Test Case Sequence

1. Start the MCPTT system.
2. Establish an MCPTT call.
3. Talk to the microphone, in order to generate all the audio transmission and messages to be recorded for the measurement (as explained before)
4. Finish the call.
5. Calculate and record the average MCPTT mouth-to-ear delay per iteration as defined in "Calculation process and output".
6. Repeat steps 1 to 5 for each one of the 25 iterations.
7. Compute the KPIs as defined in section "Calculation process and output".
</td></tr>
</table>

3.14 Application Specific KPIs

3.14.1 Video Stream Jitter

Test Case		TC_JIT_VideoStreamJitter_MAL	VideoStreamJitter
1	*Target KPI* ***Video Stream Jitter*** The jitter test aims to assess the measurement capabilities of the measurement system employed in future jitter tests. Measurement probes may be virtualized or physical. In case of virtualized probes, all probes shall be instantiated on the same (physical) host. In case of physical probes, the latter shall be preferably directly connected. Source of packets → video transmitter Destination of packets → video receiver Underlying SUT → Network components between the source and destination Measurement conducted at layer → Application layer		
2	*Methodology* For measuring jitter, a RTP (Real Time Protocol) stream is emitted from a source and received by a data sink (destination). The amount of data (Byte) successfully transmitted per unit of time (seconds) and received shall be recorded. The test case shall include the consecutive execution of several iterations according to the following properties. • Duration of a single iteration → at least two (2) minutes. • Records RTP stream received. • Number of replica → At least 25 iterations.		
3	*Calculation process and output* The results shall be calculated according to the 5GENESIS Statistical Processing Methodology. Note: In each iteration, the jitter is calculated according to RFC 3550 (RTP).		
4	*Complementary measurements* • PL rate is recorded in order to detect jitter peaks due to packet lost. • Inter-packet delay The results shall be calculated according to the 5GENESIS Statistical Processing Methodology.		

5	*Pre-conditions* • The scenario has been configured. • The traffic generator should support the generation RTP video traffic. • Ensure that no undesired traffic is present during the test.
6	*Applicability* The measurement probes need to be capable of recording the traffic received.
7	*Test Case Sequence* 1. Start monitoring probes (deployment of probes running iPerf client and server). 2. Using the traffic generator, begin transmitting from the server to the client. 3. Record the traffic for each time interval within a trial. 4. Stop the traffic generator. 5. Stop monitoring probes. 6. Calculate and record the KPIs as needed per iteration as defined in "Calculation process and output". 7. Repeat steps 1 to 6 for each one of the 25 iterations. 8. Compute the KPIs as defined in section "Calculation process and output".

3.14.2 Packet Delays (HTTP POST)

Test Case		*TC_IoT_PacketDelayHTTP_POST_SUR*	*Packet delay (app pov)*
1	*Target KPI* The main KPI is ‘packet delays’. Under increasing load (various sampling rates), the server is able to receive, treat (decoding JSON and storing data in MySQL database) and answer all HTTP POST requests without accumulating delays.		
2	*Methodology* One IoT board using HTTP POST publishes 4 batches of data (resp. 1,10,100,1000). The average delay is calculated for each batch. We may apply additional delays if the performance is not acceptable with no sampling rate (typically 2 and 5sec).		
3	*Calculation process and outputs* Average delay in handling a packet is calculated considering the time stamp at packet emission and time stamp at storage in the mySQL database, then averaged.		
4	*Complementary measurements* Check on packet loss (if any)		
5	*Pre-conditions* The IoT board is configured with HTTP POST micro-python code only and set for sending data packets at various sampling rates. At the server side the HTTP server and mySQL database are up and running.		
6	*Applicability* HTTP Server and mySQL database (empty)		
7	*Test Case Sequence* 1/ start mySQL database server, 2/ start HTTP Apache server, 3/ start the IoT board, 4/ start monitoring and performing measurement.		

3.14.3 Packet Delays (MQTT)

Test Case		TC_IoT_PacketDelayMQTT_SUR_001	Packet delay (app pov)
1	*Target KPI* The main KPI is 'packet delays'. Under increasing load (various sampling rates), the MQTT client at the server side is able to receive and treat (retrieving data from the queue and storing data in mySQL database) and answer all MQTT publish requests from the IoT boards without losing data		
2	*Methodology* One IoT board using MQTT publishes 4 batches of data (resp. 1,10,100,1000). The average delay is calculated for each batch. We may apply additional delays if the performance are not acceptable with no sampling rates (typically 2 and 5sec).		
3	*Calculation process and output* Average delay in handling a packet is calculated considering the time stamp of emission and time stamp at storage in the mySQL database, then averaged.		
4	*Complementary measurements* Check on packet loss (if any)		
5	*Pre-conditions* The IoT board is configured with MQTT micro-python code only and set for sending data packets at various sampling rates. At the server side the MQTT client and mySQL database are up and running.		
6	*Applicability* HTTP Server and mySQL database (empty)		
7	*Test Case Sequence* 1/ start mySQL database server, 2/ start Mosquito, 3/ start the IoT board, 4/ start monitoring and performing measurement.		

3.14.4 Packet Delays (CoAP)

Test Case		TC_IoT_PacketDelayCoAP_SUR	Packet delay (app pov)
1	*Target KPI* The main KPI is 'packet delays'. Under increasing load (various sampling rates), the CoAP server is able to receive, treat (retrieving data from the queue and storing data in mySQL database) and answer all CoAP POST requests from the IoT boards without losing data.		
2	*Methodology* One IoT board using CoAP publishes 4 batches of data (resp. 1,10,100,1000). Collecting data from the IoT board sensors and sending it as one IoT packet takes approximately 1.1sec with a sampling rate equal to 0. The average delay is calculated for each batch. We may apply additional delays if the performance is not acceptable with 0 delay (typically 2 and 5sec).		
3	*Calculation process and output* Average delay in handling a packet is calculated considering the time stamp at emission and time stamp at storage in the mySQL database, then averaged.		
4	*Complementary measurements* Check on packet loss (if any)		
5	*Pre-conditions* The IoT board is configured with CoAP micro-python code only and set for sending data packets at various sampling rates. At the server side the CoAP (CoAPthon based) server and mySQL database are up and running.		
6	*Applicability* CoAP server and mySQL database (empty)		
7	*Test Case Sequence* 1/ start mySQL database server, 2/ start CoAP server, 3/ start the IoT board, 4/ start monitoring and performing measurement.		

3.14.5 Packet Delay (MQTT over LoRA)

	Test Case	TC_IoT_PacketDelayMQTToverLoRA_SUR	*Packet delay (app pov)*
1	*Target KPI* The main KPI is 'packet loss'. Under increasing dataflow (various sampling rates), the LoRA-dedicated MQTT client is able to receive, treat (retrieving data from the queue and storing data in mySQL database) and handle all IoT packets received from the MQTT Subscribe without accumulating delays.		
2	*Methodology* One IoT board publishes 4 batches of IoT data (resp. 1,10,100,1000) using LoRA Send along the IoT board-ID topic. The average delay is calculated for each batch. We may apply additional delays if the performance are not acceptable with 0 delay (typically 2 and 5sec or more).		
3	*Calculation process and output* Average delay in handling a packet is calculated considering the time stamp at emission and time stamp at storage in the mySQL database, then averaged.		
4	*Complementary measurements* Check on packet loss (if any).		
5	*Pre-conditions* The IoT board is configured with LoRA micro-python code. At the server side the LoRA-dedicated MQTT client and the MQTT server and mySQL database are up and running. The MQTT client has subscribed to the board-id topic and is configured with the needed TTN security credentials. The board payload (sent as an sequence of bytes) is decoded using a custom javaScript decoder which translates the received sequence of bytes into the same JSON structure as used for the WIFI cases.		
6	*Applicability* MQTT Server and MySQL database (empty)		
7	*Test Case Sequence* 1/ start mySQL database server, 2/ start MQTT server, 3/ start the IoT board, 4/ start monitoring and performing measurement.		

3.14.6 360º Live Video Streaming QoE

Test Case		TC_360LiveVideoStreamingQoE_BER	*Video QoE*
1	*Target KPI* **360° Live Video Streaming Quality of Experience** The aim of this Test Case is to assess the Quality of Experience (QoE) perceived by users streaming a 360° live video service. This is a user QoE KPI, hence it is composed by several metrics which contribute to the QoE assessment.		
2	*Methodology* Once a scenario under test (e.g., outdoor deployment) is chosen and the end-to-end network is configured to deliver a live video service, the following metrics has to be collected for each user streaming the video contents: • Time spent in different player states (startup, playing, stalling) • Time spent on different bit rate levels while "playing" • Rebuffering events • Startup times per impression • Quality switches In order to provide reliable statistics, the above indicators must be collected for a long-enough time interval, depending on the expected duration of the live video service.		
3	*Calculation process and output* Once the parameters are collected, the main statistical indicators can be derived, i.e., • **Average time** spent in different player states • **Total time** spent on different bit rate levels while "playing" • **Statistics** of the frequency of rebuffering events • **Statistics** of Startup times per impression • **Frequency** of quality switches		
4	*Complementary measurements* Parameters related to the conditions of the network components involved in the end-to-end video delivery (e.g., RTT and throughput between well-specified network end-points, including radio and core functions) should be collected in parallel to the above QoE indicators, in order to assess correlations and causalities between user QoE and network conditions.		
5	*Pre-conditions* • The end-to-end system is configured and the QoE data collectors are ready to use.		

6	*Applicability* N/A
7	*Test Case Sequence* 1. Initialize the live video service and QoE data collectors 2. Collect the QoE data defined in "Methodology" 3. Derive the main statistics defined in "Calculation process and output"

4 Traffic Profiles

4.1 ICMP ECHO REQUEST-ECHO RESPONSE Traffic

The amount of data in an IP packet of type ICMP ECHO_REPLY will always be 8 bytes more than the requested payload, due to the ICMP header.

4.1.1 24-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_32*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards. The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds • Length of Data Field in the ICMP ECHO_REQUEST → 24 bytes	
2	Service Type (optional) *n/a*	

4.1.2 56-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_64*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards. The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds • Length of Data Field in the ICMP ECHO_REQUEST → 56 bytes	
2	Service Type (optional) *n/a*	

4.1.3 120-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_128*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards.	

	The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds • Length of Data Field in the ICMP ECHO_REQUEST → 120 bytes
2	Service Type (optional) *n/a*

4.1.4 504-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_512*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards. The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds • Length of Data Field in the ICMP ECHO_REQUEST → 504 bytes	
2	Service Type (optional) *n/a*	

4.1.5 1400-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_1408*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards. The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds • Length of Data Field in the ICMP ECHO_REQUEST → 1400 bytes	
2	Service Type (optional) *n/a*	

4.1.6 1492-byte-payload ECHO_REQUESTS

Traffic Description		*TP_ICMP_1500*
1	Traffic sources ICMP ECHO_REQUEST – ICMP ECHO_RESPONSE traffic stream between source and destination and backwards. The stream of generated ICMP ECHO_REQUESTs shall comply to the following specification: • Time Interval between sending each packet → 0.5 seconds	

	• Length of Data Field in the ICMP ECHO_REQUEST → 1492 bytes
2	Service Type (optional) *n/a*

4.2 TCP/UDP Traffic

4.2.1 UDP Traffic

Traffic Description		*TP_UDP_1400*
1	Traffic sources UDP traffic stream between source and destination and backwards. The stream of generated UDP packets shall comply to the following specification: • Length of UDP datagaram (UDP header + UDP payload) → 1400 bytes • The bandwidth depends on test purpose. For maximum user data rate tests the bandwidth should be set above the maximum bandwidth available in the network scenario.	
2	Service Type (optional) *n/a*	

5 Overview of Specifications on EE KPIs and metrics for mobile networks

Telecommunication networks energy efficiency KPIs are defined by various SDOs / organizations and are of various natures [14]. They can be applied to either:

- whole networks (i.e. E2E), or to
- sub-networks (e.g. the RAN), or to
- single network elements, or to
- telecommunication sites, which contain network elements and site equipment.

Moreover, EE KPIs can also be categorized according to the operator's network life cycle phase they may apply to, e.g.:

- during the equipment procurement phase, mobile network operators may be willing to compare network elements from various vendors from an EE standpoint. Some EE KPIs and measurement methods have been specified for this purpose.
- during the Design / Build phase, mobile network operators are always faced to several design options and may be willing to compare them from an EE standpoint. This may happen for the whole network, sub-networks and for telecom sites. For telecom sites, EE KPIs have been specified.
- during the Run phase, mobile network operators need to assess the energy efficiency of the live network, as a whole (i.e. end-to-end), or for sub-networks, or for single network elements or telecom sites. Some EE KPIs and measurement methods have also been specified for this purpose.

Generally, EE KPIs for network elements are expressed in terms of Data Volume divided by the Energy Consumption of the considered network elements. In the case of radio access networks, an EE KPI variant may also be used, expressed by the Coverage Area divided by the Energy Consumption of the considered network elements.

In the remainder of this ANNEX, an overview of the main standards /recommendations addressing EE KPIs and metrics for mobile networks is provided. The list includes:

- **ETSI ES 202 706-1 (2017)**
- **ETSI ES 102 706-2 (2018)**
- **ETSI ES 203 228 (2017)**
- **ITU-T** Recommendation **L.1330 (2015)**
- **ITU-T** Recommendation **L.1331 (2017)**
- **ITU-R** Recommendation **M.2083 (2015)**
- **NGMN 5G whitepaper (2015)**
- **3GPP TR 38.913 (2018)**
- **3GPP TR 21.866 (2017)**
- **3GPP TR 32.972 (2018)**
- **3GPP TR 32.856 (2017)**

ETSI ES 202 706-1 (2017)

The ETSI ES 202 706-1 specification [15] defines methods to **evaluate the power consumption of base stations** (for GSM, UMTS and LTE) in **static mode**. These methods can be used by i) telecom equipment manufacturers in their labs. Measured KPIs are generally captured in product specification datasheets; and ii) MNOs may use such measurements to compare equipment from different vendors from an EE point of view. They can also make their own measurements in their own labs in order to check if they have the same results. The specification describes methods for:

- Average power consumption of BS equipment under static test conditions: the BS average power consumption is based on measured BS power consumption data under static condition when the BS is loaded artificially in a lab for three different loads, low, medium and busy hour under given reference configuration.
- **Daily average power consumption of the base station.**

Sections 7.2 & 7.3 of the specification describe calculation methods of **average static power consumption for integrated and distributed BS configurations** respectively. In [14] under static test conditions, the Base Station (BS) average power consumption is based on measured BS power consumption data when the BS is loaded artificially in a lab for three different loads (low, medium and busy hour) under given reference configuration.

The **power consumption of integrated BS equipment in static method** is defined for three different load levels as follows:

- P_{BH} is the power consumption [Watts] with busy hour load.
- P_{med} is the power consumption [Watts] with medium term load.
- P_{low} is the power consumption [Watts] with low load.

The load levels are defined differently for different radio systems. The model covers voice and/or data hour per hour. The models are provided in the annexes D, E, F of [15].

The **power consumption of distributed BS equipment in static method** is defined for three different load levels as follows (for details of load levels see the annexes D, E and F in [15]):

- $P_{BH,C}$ and $P_{BH,RRH}$ are the power consumption [W] of central and remote parts of BS with busy hour load.
- $P_{med,C}$ and $P_{med,RRH}$ are the power consumption [W] of central and remote parts of BS with medium term load.
- $P_{low,C}$ and $P_{low,RRH}$ are the power consumption [W] of central and remote parts of BS with low load.
  - **Note that ETSI ES 202 706-1 defines daily average power consumption of GSM/WCDMA/LTE/WIMAX base stations, defined for three different load levels, in a lab-based test setup (Measurement Lab Setup for STATIC power consumption measurements is provided in section 6.1.1 in [15]). The templates for test reporting are provided in ANNEX A, and Reference parameters for LTE system in ANNEX F of [15] respectively.**

ETSI ES 102 706-2 (2018)

The ETSI ES 102 706-2 [16] document defines the **dynamic measurement method** (section 6.2) and defines **base station energy efficiency KPI** (section 6.2.11). Under dynamic test conditions, the BS capacity is measured under dynamic traffic load provided within a defined coverage area and the corresponding power consumption is measured for given reference configurations. Dynamicity of measurements may be achieved thanks to dynamic load, activation / deactivation of radio network features, various user terminals performance and distribution. The results can be used to assess and compare the energy efficiency of base stations.

The TR defines the dynamic measurement method for evaluation energy efficiency:

- **BS EE** under dynamic load conditions: the BS capacity under dynamic traffic load provided within a defined coverage area and the corresponding energy consumption is measured for given reference configurations.
- ETSI ES 202 706-1 [15] defines **daily average power consumption** of the base station.

The base station energy efficiency KPI is an indicator for showing how a base station in an energy efficient way is doing work in terms of delivering useful bits to the UEs served by the base station. A base station is more energy efficient when doing more work with the same energy, doing the same work with less energy or in the best case doing more work with less energy. **The base station energy efficiency KPI is the ratio of delivered bits and consumed energy (reported in units of bits/Wh)** and is denoted by:

$$BSEP = \frac{DV_{total}}{E_{equipment}^{total}} \qquad (1)$$

Where DV_{total} is the total delivered bits during the measurement for all three traffic levels according to section 6.2.6 in [15] and $E_{equipment}^{total}$ is the total consumed energy during the measurement period for delivering DV_{total} according to section 6.2.8 in [15].

Data Volume Measurement

All received data by the UEs during each measurement period for each traffic level shall be measured. The measured data is the net data volume and shall not contain any duplicated or retransmitted data. The data shall be generated as described in section 6.2.3 and annex C in [15]. The measured data will be used for calculation of BS efficiency KPI and is in bits.

Since the time period for the three load levels in a real network under a 24-hours period is different, three weighting factors are applied to the measurement results to reflect the time ratio of low load, medium load and busy-hour load levels in a 24-hours period respectively.

These weighting factors are denoted as W_{low} for low traffic, W_{medium} for medium traffic and $W_{busy\text{-}hour}$ for busy-hour traffic level and they are defined in annex C in [15].

The measured data volume in bits for low load level is denoted as $DV_{measured\text{-}low}$.

The measured data volume in bits for medium load level is denoted as $DV_{measured\text{-}medium}$.

The measured data volume in bits for busy-hour load level is denoted as $DV_{measured\text{-}busy\text{-}hour}$.

The total data volume for 24-hours period is calculated as following:

$$DV_{total} = \left(DV_{low} \times \frac{W_{low}}{T_{measurement\ low}}\right) + \left(DV_{medium} \times \frac{W_{medium}}{T_{measurement\ medium}}\right) + \left(DV_{busy\ hour} \times \frac{W_{busy\ hour}}{T_{measurement\ busy\ hour}}\right)\ [bits] \qquad (2)$$

The three load levels shall be measured at middle frequency channel.

EC Measurement

The energy consumption of the base station under test shall be calculated during the whole measurement period. The total energy consumption of the base station will be the sum of weighted energy consumption for each traffic level i.e. low, medium and busy-hour traffic. Since the time period for the three load levels in a real network under a 24-hours period is different, three weighting factors are applied to the measurement results to reflect the low load, medium load and busy-hour load levels in a 24-hours period respectively. These weighting factors are denoted as W_{low} for low traffic, W_{medium} for medium traffic and $W_{busy\text{-}hour}$ for busy-hour traffic level and they are defined in annex C.

To calculate the energy consumption, the power consumption of the BS is sampled continuously (interval time Δt_m: 0,5 seconds or shorter) over the complete measurement period for each traffic level. For the integrated BS, is the measured power value for the i[th] sampled measurement during the measurement period. The energy which is the energy consumption of the BS during the measurement is calculated as follows:

$$E_{equipment}^{traffic\_scenario\_x} = \sum_{k=1}^{n}\left(\Delta t_m \cdot P_{k,equipment}^{traffic\_scenario\_x}\right) \text{[Wh]} \quad (3)$$

For the distributed BS, $E_{C,\ equipment}$ and $_{ERRH,\ equipment}$ [Wh] are the energy consumption of the central and the remote parts in the dynamic method defined as:

$$E_{RRH,equipment}^{traffic\_scenario\_x} = \sum_{k=1}^{n}\left(\Delta t_m \cdot P_{k,RRH,equipment}^{traffic\_scenario\_x}\right) \text{[Wh]} \quad (4)$$

$$E_{C,equipment}^{traffic\_scenario\_x} = \sum_{k=1}^{n}\left(\Delta t_m \cdot P_{k,C,equipment}^{traffic\_scenario\_x}\right) \text{[Wh]} \quad (5)$$

Where $n = \frac{T_{measurement}}{\Delta t_m}$, and $T_{measurement}$ is the measurement time for each traffic level and Δt_m is the sampling period.

The measured energy consumption in Wh for low load level is denoted as $E_{equipment}^{measured-traffic\_scanrio\_low}$.

The measured energy consumption in Wh for medium load level is denoted as $E_{equipment}^{measured-traffic\_scenario\_medium}$.

The measured energy consumption in Wh for busy-hour load level is denoted as $E_{equipment}^{measured-traffic\_scenario\_busy-hour}$.

The total energy consumption for 24-hours period is calculated as following:

$$E_{total\ equipment} = \left(E_{low} \times \frac{W_{low}}{T_{measurement\ low}}\right) + \left(E_{medium} \times \frac{W_{medium}}{T_{measurement\ medium}}\right) + \left(E_{busy\ hour} \times \frac{W_{busy\ hour}}{T_{measurement\ busy\ hour}}\right) [Wh] \quad (6)$$

For the calculation of the total energy consumption for distributed BS similar calculation as above for radio remote part and the central equipment part formulas (6.2) to (6.6) can be used. The sum of each part and then summing up these two parts to obtain the total energy consumption for a distributed BS.

- **Note that ETSI ES 102 706-2 defines LTE base station energy efficiency KPI based on total data volume & energy consumption for 24-hour period, defined for three different load levels, in a lab-based test setup (Measurement Lab Setup provided in section 6.2.1 in [12]). The templates for test reporting are provided in ANNEX A, and Data Traffic Models in ANNEX C of [15] respectively.**

ETSI ES 203 228 (2017)

The ETSI ES 203 228 [17] **defines energy efficiency metrics and measurement procedures in operational radio access networks.** Two high-level EE KPIs are defined:

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

in which Mobile Network data Energy Efficiency ($EE_{MN,DV}$), expressed in bit/J, is the ratio between the performance indicator (i.e. Data Volume DV_{MN}) and the energy consumption (EC_{MN}), and

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

in which $EE_{MN,CoA}$, expressed in m²/J, is the ratio between the coverage area (CoA-des$_{MN}$) and the energy consumption EC_{MN}. EC_{MN} is the yearly energy consumption and $\mathrm{CoA_des_{MN}}$is the "coverage area" as defined in section 6.2.3].

This specification/recommendation considered as a point of reference also by 3GPP (SA and RAN) that deals with the methods and metrics to evaluate **EE for mobile radio access networks**, encompassing GSM, UMTS and LTE.

MN EC Measurement

The Mobile Network Energy Consumption (EC_{MN}) is the sum of the energy consumption of equipment included in the MN under investigation (see section 4). The network energy consumption is measured according to the assessment process defined in section 6 such that individual metrics are provided per RAT and per MNO. **The overall EC of the partial network under test** is measured as follows:

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

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.
- 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.

EC_{MN} shall be measured in Wh over the period of measurement T.

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

– ICT equipment (equipment directly needed to perform the telecom service).

– Support equipment (all equipment installed at the site which are needed to operate the particular site, but which are not directly needed for the telecom 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 telecom equipment with reference to the total energy consumption shall be introduced:

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

The above site energy efficiency **(SEE) metric gives an INDICATION of site energy efficiency (SEE)** in terms of how big fraction of energy is used for actual telecom equipment (telecommunication service delivery).

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.

Data Volume Measurement

The Mobile Network performance metrics is derived from parameters of the MN under investigation (see section **Error! Reference source not found.**) 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 section **Error! Reference source not found.** 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 section 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 section 6). *i* and *k* are like in formula (1).

Note that by "circuit switched", we mean here all voice, 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 section 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 [18] (3GPP TS 32.425) and ETSI TS 132 412 [20] (3GPP 32.412) for LTE or equivalent used for 2G and 3G, multiplying by the measurement duration T. The counters (in [18] and [19]) account also for QoS being reported in QoS Class Identifier (QCI) basis (see [20]).

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 computed in unit of bit.

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 section 6 shall be used. CoA is computed in unit of m^2.

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 present in the MN under test. Data volume shall be measured in an aggregated way per each RAT present in the MN and **shall be measured referring to counters derived from vendor O&M systems.**

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

$$Call\ Success\ Rate = (1 - dropping\ rate) \times 100\ [\%] \qquad (5)$$

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:

$$1 - \text{dropping rate} = (1 - \text{intracell failure rate})(1 - \text{handover failure rate}) \qquad (6)$$

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** that is out of scope of the present document.

NOTE 2: As soon as the MDT related measurements in [18] are available the data volume may be measured according to the specification given therein (especially referring to section 4.1.8 in [18]). In this case, the per-user information about QoS can be obtained for data services and only connections with good QoS should be considered.

Coverage Area Measurement

The Coverage area is subject to network planning and intended services delivered within a certain geographic area. The coverage area shall be described by the following parameters:

- The total geographical area of a country (CoA_geo). This includes the total geographical area which falls into the network operator 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).
- The designated coverage area (CoA_des). This area defines the area in which a network coverage is provided by the selected sub-network and is derived by planning models from network design, planned service and geographical data.
- A coverage quality factor (CoA_Qdes). This factor considers measured feedback from user equipment (as described in table 8 in [17]). This coverage quality factor signifies that networks

might experience false coverage issues (e.g. inside buildings), load congestions or high interference issues.

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 is a measure to estimate the actually covered fraction of the planned total coverage area. User equipment reports such as failed call attempts (table 1) 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) 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. 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 know how many users/sessions or served users/sessions experienced problems because of lack of sufficient quality in relation to the total number of users/sessions or served users/sessions within the considered area. This allows a number of simplifications and an indirect determination of 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:

$$\text{CoA\_Qdes} = 1 - \text{"percentage of users/sessions with coverage failure"} \quad (7)$$

The following indicators shall be used to calculate the coverage failure (details see table 8 [14]):

- RRC setup failure ratio (Call setup failure ratio).
- RAB setup failure ratio (UE-BS radio interface failure).
- 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:

$$\text{CoA\_Qdes} = (1 - \text{RRC setup failure ratio})\ (1 - \text{RAB setup failure ratio})\ (1 - \text{RAB release failure ratio}) \quad (8)$$

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 = (Σk Failed RRC connection establishmentsk)/(Σk Attempted RRC connection establishmentsk).
- RAB setup failure ratio = (Σk RAB setup failurek)/(Σk RAB setup attemptedk).
- RAB release failure ratio = (Σk RAB release failurek)/(Σk RAB release attemptedk).

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

Table 1: Measurement parameters required for LTE coverage quality calculation
(source reference : [17])

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*

The following averaging procedure is then used to obtain an average coverage quality factor (which needs to be reported along with $\text{CoA\_des}_{\text{MN}}$) of the partial network under test:

$$\text{CoA\_Qdes}_{\text{MN}} = \sum_{\text{i}} \text{CoA\_Qdes}_{\text{S}_\text{i}} \text{DCA}_{\text{S}_\text{i}} / \text{CoA\_des}_{\text{MN}} \quad (9)$$

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 sites designed coverage areas should be defined as the area where the signals from the cells of the site are stronger (Best Server). It holds true that:

$$\text{CoA\_des}_{\text{MN}} = \sum_{\text{i}} \text{DCA}_{\text{S}_\text{i}} \leq \text{CoA\_geo} \quad (10)$$

where:

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

Finally, ETSI ES 203 228 [17] defines a method to define sub-networks from which these EE KPIs are calculated and to extrapolate them to the operator's whole radio access network. **The EE measured for sub-network can be extrapolated to larger networks.** The extrapolation approach is discussed in section 7.

For data reporting templates, see ANNEX A in ES 203 228 or equivalent in ANNEX I of Rec. ITU-T L.1331.

- Note that ETSI ES 203 228 defines RAN energy efficiency KPI based on total data volume & energy consumption, over weekly/monthly/yearly periods, defined independently of load levels, in operational networks, for a sub-network (or partial network, denoted as the Mobile Network under investigation) comprising:
  - Base stations (e.g. Wide area BS, Medium range BS, Local Area BS, Home BS).
  - Site equipment (air conditioners, rectifiers/batteries, fixed network equipment, etc.).
  - Backhaul equipment required to interconnect the BS used in the assessment with the core network.
  - Radio Controller (RC).

ITU-T Recommendation **L.1330 (2015)**

The ITU-T Recommendation L.1330 [21] is considered as a point of reference also by 3GPP (SA and RAN) that deals with the methods and metrics to evaluate EE for mobile radio access networks, encompassing GSM, UMTS and LTE. The recommendation provides principles and concepts of energy efficiency metrics and measurement methods for telecommunication network equipment.

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

This Recommendation was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published respectively by ITU and ETSI as **Recommendation ITU-T L.1330 [21] and ETSI Standard ETSI ES 203 228 [17],** which **are technically equivalent**. This Recommendation describes the energy consumption (EC) and mobile network (MN) energy efficiency measurements in **operational networks.**

ITU-T Recommendation L.1310 (2017)

The ITU-T Recommendation L.1310 [22] specifies the principles and concepts of energy efficiency metrics and measurement methods for telecommunication network equipment. This Recommendation also specifies the principles and concepts of energy efficiency metrics and measurement methods for small networking equipment (Metric for DSLAM, MSAM GPON GEPON equipment) used in the home and small enterprise locations.

ITU-T Recommendation L.1331 (2017)

The Recommendation ITU-T L.1331 [23] considers the definition of metrics and methods used to measure energy efficiency performance of mobile radio access networks and adopts an approach based on the measurement of such performance on small networks, for feasibility and simplicity purposes. Such a simplified approach is proposed for approximating energy efficiency evaluations and cannot be considered as a reference for planning evaluation purposes throughout the network operation process. The same approach was introduced in ETSI TR 103 117 [24]; the measurements in testing laboratories of the efficiency of the base stations is the topic treated in ETSI ES 202 706-1 [14].

The Recommendation also provides an extrapolation method to extend the applicability of the assessment of energy efficiency to wider networks. The Recommendation was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published by ITU-T and ETSI as **Recommendation ITU-T L.1331 [23] and ETSI ES 203 228 [17]** respectively, which **are technically equivalent.** This Recommendation describes the energy consumption (EC) and mobile network (MN) energy efficiency measurements in o**perational networks.**

ITU-R Recommendation M.2083 (2015)

The Recommendation M.2083 [42] establishes the vision for IMT for 2020 and beyond, by describing potential user and application trends, growth in traffic, technological trends and spectrum implications. With regards to Energy efficiency, the recommendation indicates that EE has two aspects: i) 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); ii) 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 recommendation also stipulates that: 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.

NGMN 5G whitepaper (2015)

Next Generation Mobile Networks (NGMN) White Paper [25] 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 of [25] 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.

3GPP TR 38.913 (2018)

The 3GPP TR 38.913 [26] 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 [25], one paragraph is dedicated to “UE energy efficiency” (7.12), another one (7.14) to “Area traffic capacity” and the “User experienced data rate”. These two latter KPIs are relevant for the Energy Efficiency estimation. Finally, paragraph 7.19 is dedicated to “Network energy efficiency”. In such paragraph, it is clearly stated that “Network energy efficiency shall be considered as a basic principle in the NR design”. 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 defined as

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

where

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

b_k refers to the weights of every deployment scenario where the network energy efficiency is evaluated.

V_1 **r**efers to the traffic per second served by a base station (in bits/s)

EC_1 refers to the power consumed by a base station to serve V_1 (in Watt = Joule/s).

a_1 refers to the weight for each traffic load level.

EC” is the power consumed by a base station to serve V.

The suggested KPIs in this 3GPP TR are for use in simulations. For the calculation of the above KPIs, the following assumptions are made:

- Energy Efficiency Quantitative KPI should be **evaluated by means of system level simulations at least in 2 deployment scenarios**: one coverage limited environment (ex: Rural) AND one capacity limited environment (ex: Urban);

- Evaluation should not be for peak hour but based on a **24-hour daily traffic profile**.

- It is recommended that at least 3 load levels should be evaluated.

3GPP TR 32.972 (2018)

The 3GPP TR 36.927 [28] provides an overview of studies and/or normative works initiated by other SDOs / working groups on pre-5G and/or 5G radio access networks energy efficiency. It also inventories high-level EE KPIs defined by those SDOs / working groups and methods to collect required measurements. The study identifies potential use cases and requirements for i) 5G network energy efficiency assessment (measurement & reporting) and ii) energy efficiency optimization (i.e. energy saving).

3GPP TR 32.856 (2017)

The 3GPP TR 32.856 [29] reports how 3GPP OAM specifications can provide support for the assessment of energy efficiency in radio access networks as defined by ETSI ES 203 228 [16], thanks to measuring both network performance and energy consumption. It provides a gap analysis between [16] and 3GPP OAM Technical Specifications.

Measurement methods

Existing measurement methods

Existing measurement methods [14] for the calculation of EE KPIs for mobile networks (cf. ETSI ES 203 228 [17], ETSI ES 202 706-1 [15] and 3GPP TR 21.866 [27]) are based on the collection, on a per network node basis, of:

- Data Volume measurements, and
- Energy Consumption measurements.

In some deployment scenarios of radio access networks, Coverage Area measurements may be used instead of Data Volume measurements.

Data Volume measurements are collected via OAM, as performance measurements, e.g. as recommended in ETSI ES 203 228 [17] for radio access networks.

Energy Consumption information can be collected:

- using power meters or information from invoices provided by power suppliers,
- via built-in sensors, e.g. in case base stations (cf. ETSI ES 202 336-12 [30]), enabling the collection of energy consumption measurements via OAM,
- via external sensors and XCU/DGU, as specified in ETSI ES 202 336-12 [30].

The methodology may vary depending on whether the measurements are made in live networks or in test laboratories.

- In laboratories, ETSI ES 202 706-1 [15] defines a two-level assessment method to be used to both evaluate power consumption and energy efficiency of base stations. The two levels are:

- Base station equipment average power consumption for which it defines reference base station equipment configurations and reference load levels to be used when measuring base station power consumption.

- Base station equipment energy efficiency, defined as the measured capacity for a defined coverage area, divided by the simultaneously measured energy consumption.

- In live networks, ETSI ES 203 228 [17] recommends to split the total mobile network operator network 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.

The measurement method defined in ETSI ES 203 228 [17] for sub-networks provides the basis to estimate energy efficiency for large networks of one mobile network operator or within an entire country, applying extrapolation methods.

Potential measurement methods for 5G networks

The calculation of an EE KPI will rely on the collection of related measurement data of two types:

- Data volumes:
  - the reporting method (reporting Method) of data volumes for 5G network elements / functions will be specified in TS 28.550 [31] for stage 1, stage 2 and stage 3,
  - the measurements (e.g. counters) will be defined in TS 28.552 [32] for the 5G radio access network and the 5G core network.

- Energy consumption:
  - for non-virtualized parts of base stations, regardless of whether these base stations are equipped with built-in or external sensors, their energy consumption can potentially be collected via XCU/DGU and/or VS-RMS and/or their EM/DM (see Note 1), as specified in TS 28.304 [33], TS 28.305 [34] and TS 28.306 [35]. This potentially applies to non-virtualized core network elements as well;
  - for virtualized parts of base stations, the energy consumption of the Virtualized Network Functions (VNFs) is the energy consumption of the server(s) on which the VNF(s) run, minus the energy consumption of the subject servers when they are in idle mode. When multiple VNFs run simultaneously on a given server, how to measure their respective part in the overall energy consumption of the server is not specified. This potentially applies to virtualized core network functions as well.

NOTE 1: The measurement method described in ETSI ES 203 539 [36] is intended to be used to assess and compare the energy efficiency of VNFs in lab testing and pre-deployment testing; it aims not to define measurement method in operational NFV environment. In particular, it does not specify how the energy consumption of each server is measured individually in an operational environment.

Energy efficiency assessment in 5G

The assessment of energy efficiency of 5G networks may be based on the following potential solutions:

- 5G base stations are assumed to be all equipped with built-in sensors (cf. ETSI ES 202 336-12 [30]);
- Object model definition: the attribute 'peeParametersList' of IOC ManagedFunction, defined in TS 28.622 [37], may be used to model the PEE related parameters;
- Management services for network function provisioning, defined in TS 28.531[38], may apply to read / write PEE related parameters and notify PEE related parameters value changes;
- Data volume measurements required to calculate DV (Data Volume) are to be defined in TS 28.552 [32]. KPIs may have to be defined in TS 28.554[39];
- Power, Energy and Environmental (PEE) measurements required to calculate EC (Energy Consumption) are to be defined in TS 28.552 [32];
- The 'Measurement job control services for NFs', defined in TS 28.550 [31], may apply for the collection of DV and EC performance measurements data;
- The 'Performance data file reporting services for NFs, defined in TS 28.550 [31], may apply for the file-based reporting of DV and EC performance measurements data.

Upcoming specifications on EE in 5G mobile networks

The 3GPP SA5 WG, recommends starting normative work on the i) definition of use cases and requirements for 5G network energy efficiency assessment and optimization, ii) definition of performance measurements / KPIs enabling to assess the energy efficiency of 5G networks, for both aspects: data volumes and energy consumption, iii) definition of solutions for energy saving management in 5G networks.

The metrics and methods described in ES 203 228 [17]/ITU-T L.STP 5GEE for the legacy networks are considered valid for 5G Phase 1 (focus on eMBB) and an update will be issued once the 5G Phase 1 details are standardized.

The Phase 2 of 5G (rel. 16 and beyond), will impact heavily the specifications to measure energy efficiency and will require an extensive update of ETSI/ITU specifications, 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.

In summary, for 5G phase 1 [rel.15]:

- For operational networks, EE KPIs for whole or partial RAN, should be evaluated according to ITU-T L.1331 recommendation (or ETSI ES 203 228 which is equivalent).
- For lab-based test networks, EE KPIs for a base station, can be evaluated according to ETSI ES 202 706-1 and ETSI ES 102 706-2 for both static and dynamic operations.
- For simulation-based studies, EE KPIs for a base station, can be evaluated according to 3GPP TR 21.866 and 3GPP TR 38.913.

6 EE Assessment Reporting Templates

The assessment report shall include tables defined below. Items in italics can be considered optional. Further guidelines on the test report can be found in clause 5.10 of ISO/IEC 17025.

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 $\mathrm{CoA\_des}_{\mathrm{MN}}$ is instead computed starting from the area covered by each site and aggregating for all the sites in the Network Area under test.

For each site reported in Table Table 5 the details shall be included in Table 6. Table 7 reports the measurements results for each site.

Table 5: "Network Area under test" reporting template

Network Area under test		
Demography class [Dense Urban, Urban, Suburban, Rural, Sparse]		
Topography class		
Climate zone		
Informative classification		
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	
	Other options [indicate]	
Backhauling information		
	Predominant type of backhauling [wireless, fibre, copper…]	
	Number of backhauling links per type	
Energy efficiency in the Network Area under test		
	$EE_{MN,DV}$ [b/J]	

Network Area under test		
	$EE_{MN,CoA}$ [m²/J]	
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.		

Table 6: "Sites under test" reporting template

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, other]	
	Site "MNOs" [single MNO, co-location, network sharing, other]	
Site and equipment age • *Initial commission date of the site* • *Commission date of the current equipment in the site*		
Temperature • *Average temperature [over period T]* • *Minimum temperature* • *Maximum temperature*	*Internal °C*	*External °C*
Environmental class Temp. range IC class (for each equipment in the site) *A 0 … 28 °C IP23* *B -20 … 40 °C IP45* *C -40 … 55 °C IP45*		
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]		

Site(s) under test in the Network Area (one table per site type to be measured in the Network Area)		
Energy efficiency in the site equipment (Energy_ICTequipment/Energy_Total_network)		
- Total electrical energy supplied from the grid - Peak power delivered from the grid - Total site energy storage capacity - Peak shaving features available at the site		
Energy Efficiency Enhancement methods affecting the site equipment during the test		
Estimated percentage of presence of this site type in the Network Area		
Electricity sources used in the site		
	Electricity [%]	
	Genset [%]	
	Solar [%]	
	Renewables [%]	
	Others (indicate)	

Table 7: "Site measurement" reporting template

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	
Site Energy efficiency		
	Measured Energy Efficiency EE_{MN} [bit/J] and [m^2/J]	
	• Weekly Energy Efficiency [per week data/graph]	
	• *Monthly Energy Efficiency [if T allows]*	
	• *Yearly Energy Efficiency [if T allows]*	

Table 8 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 8: Total (whole) Mobile Network Energy Efficiency assessment

Demography Class	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***

The following equations explain how to compute the Total EE in the cases mentioned above.

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

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

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

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

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).

7 Cloud RAN Energy Efficiency

The aim of this annex is to provide the basic information on definitions and principles to be used for the assessment of energy efficiency of Cloud RAN (CRAN) networks.

As far as energy efficiency assessment is concerned, the generic architecture of CRAN can be divided in 3 domains: central cloud, edge cloud and radio access.

The Radio Access (RA) domain consists 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 would perform real time eNB tasks (e.g. Scheduler) and is installed near the transmitting antennas (e.g. within 1 m to 1 km). The density of RAP's deployed for CRAN would vary with different implementations but would be typically be of a few RAP units per 10 km^2. A typical value of RAP energy efficiency is: SEE_{RAP} = 90 %.

The Edge Cloud (EDC) domain is consisting of small datacentres dedicated to telecom functions, including Virtualized 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 density of EDC datacentres deployed for CRAN would vary with different network configurations but would typically be of a few units per 100 km^2. A typical value of Edge Cloud site energy efficiency is: SEE_{EDC} = 75 %.

The Central Cloud (CC) domain is consisting of a datacentre (DC) including Central Servers (CS), Switching Equipment (SE) and other Telco Equipment (TE). The IP Core network equipment is not be taken into account in the assessment of CRAN EE. Central Cloud datacentres are usually very far from most of the served EDC. Their density would vary with different network configurations but would typically be of a few units per 100,000 km^2. A typical value of Central Cloud site energy efficiency is: SE_{ECC} = 65 %.

The following formulas can be used in the EE assessment for CRANs [16]:

Data Volume:

$$DV_{CRAN} = \sum_{RAP}(DV_{RAP-DL} + DV_{RAP-UL})$$

where DV_{RAP-DL} and DV_{RAP-UL} are the data volume of the RAP for downlink (DL) and uplink (UL) respectively.

Energy consumption:

$$EC_{CRAN} = \sum_{CC\ sites}\left(\sum_{site}(EC_{CS} + EC_{SE} + EC_{TE})\right)/SEE_{CC} \cdot + \sum_{EDC\ sites}\left(\sum_{Site} EC_{VNFS}\right)/SEE_{EDC} + \sum_{RAP} EC_{RAP}/SEE_{RAP}$$

Energy efficiency:

$$EE_{CRAN} = DV_{CRAN}/EC_{CRAN}$$

8 REFERENCES

[1] 5GENESIS Consortium, “D2.1 Requirements of the Facility,” 2018. [Online]. Available: https://5genesis.eu/wp-content/uploads/2018/11/5GENESIS_D2.1_v1.0.pdf.

[2] 5GENESIS Consortium, “D2.2 Initial overall facility design and specifications,” 2018. [Online]. Available: https://5genesis.eu/wp-content/uploads/2018/12/5GENESIS_D2.2_v1.0.pdf.

[3] 5GENESIS Consortium, “D2.3 Initial planning of tests and experimentation,” [Online]. Available: https://5genesis.eu/wp-content/uploads/2018/12/5GENESIS_D2.2_v1.0.pdf.

[4] 5GENESIS Consortium, “Deliverable D3.5 Monitoring and Analytics,” 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.5_v1.0.pdf. [Accessed 6 2020].

[5] 5GENESIS Consortium, “The Athens Platform,” 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.5_v1.0.pdf. [Accessed June 2020].

[6] 5GENESIS Consortium, “The Malaga Platform,” 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.2_v1.0.pdf. [Accessed June 2020].

[7] 5GENESIS Consortium, “The Limassol Platform,” 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.5_v1.0.pdf. [Accessed June 2020].

[8] 5GENESIS Consortium, “Management and Orchestration,” 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.1_v1.0.pdf. [Accessed June 2020].

[9] 5GENESIS Consortium, “The Surrey Platform,” 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.11_v1.0.pdf. [Accessed June 2020].

[10] 5GENESIS Consortium, “The Berlin Platform,” 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.14_v1.0.pdf. [Accessed June 2020].

[11] 5GENESIS Consortium, “Deliverable D6.1 Trials and experimentation (cycle1),” 2019. [Online]. Available: http://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D6.1_v2.00.pdf. [Accessed June 2020].

[12] IEEE P802.11.2/D1.01 – Draft Recommended Practice for the Evaluation of 802.11 Wireless Performance. February 2008.

[13] Jain, R.: The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modelling. Wiley Professional Computing, 1991. ISBN 978-0471503361.

[14] 3GPP TR 32.972 V16.0.0 (2018-12): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Study on system and functional aspects of energy efficiency in 5G networks (Release 16).

[15] ETSI ES 202 706-1 V1.5.1 (2017-01): Environmental Engineering (EE); Metrics and measurement method for energy efficiency of wireless access network equipment; Part 1: Power Consumption - Static Measurement Method.

[16] ETSI ES 102 706-2 V1.5.1 (2018-11): Environmental Engineering (EE); Metrics and Measurement Method for Energy Efficiency of Wireless Access Network Equipment; Part 2: Energy Efficiency - dynamic measurement method.
[17] ETSI ES 203 228 (V1.2.1) (2017-04): "Environmental Engineering (EE); Assessment of mobile network energy efficiency".
[18] 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)".
[19] ETSI TS 132 425 V15.2.0 (2019-04): LTE; Telecommunication management; Performance Management (PM); Performance measurements Evolved Universal Terrestrial Radio Access Network (E-UTRAN) (3GPP TS 32.425 version 15.2.0 Release 15).
[20] ETSI TS 132 412 V15.0.0 (2018-07): Digital cellular telecommunications system (Phase 2+) (GSM);Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Performance Management (PM) Integration Reference Point (IRP): Information Service (IS) (3GPP TS 32.412 version 15.0.0 Release 15).
[21] ITU-T Recommendation L.1330 (03/2015) : Energy efficiency measurement and metrics for telecommunication networks.
[22] ITU-T Recommendation ITU-T L.1310 (07/2017): Energy efficiency metrics and measurement methods for telecommunication equipment.
[23] Recommendation ITU-T L.1331 (04/2017): Assessment of mobile network energy efficiency.
[24] ETSI TR 103 117 V1.1.1 (2012-11): Environmental Engineering (EE); Principles for Mobile Network level energy efficiency.
[25] NGMN White Paper 2015 - https://www.ngmn.org/5g-white-paper/5g-white-paper.html
[26] 3GPP TR 38.913 V15.0.0 (2018-06): 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Scenarios and Requirements for Next Generation Access Technologies; (Release 15).
[27] 3GPP TR 21.866 V15.0.0 (2017-06): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Energy Efficiency Aspects of 3GPP Standards (Release 15).
[28] 3GPP TR 36.927 V15.0.0 (2018-07): 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Potential solutions for energy saving for E-UTRAN (Release 15).
[29] 3GPP TR 32.856 V15.0.0 (2017-06): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Study on Operations, Administration and Maintenance (OAM) support for assessment of energy efficiency in mobile access networks (Release 15).
[30] ETSI ES 202 336-12 V1.2.1 (2019-02) : 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.
[31] 3GPP TS 28.550 V16.0.0 (2019-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; Performance assurance (Release 16).
[32] 3GPP TS 28.552 V16.1.0 (2019-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; 5G performance measurements (Release 16).

[33] 3GPP TS 28.304 V15.0.0 (2018-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Control and monitoring of Power, Energy and Environmental (PEE) parameters Integration Reference Point (IRP); Requirements (Release 15).

[34] 3GPP TS 28.305 V15.1.0 (2018-12): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Control and monitoring of Power, Energy and Environmental (PEE) parameters Integration Reference Point (IRP); Information Service (IS) (Release 15).

[35] 3GPP TS 28.306 V15.0.0 (2018-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Control and monitoring of Power, Energy and Environmental (PEE) parameters Integration Reference Point (IRP); Solution Set (SS) definitions (Release 15).

[36] ETSI ES 203 539 V1.1.0 (2019-03): Environmental Engineering (EE); Measurement method for energy efficiency of Network Functions Virtualisation (NFV) in laboratory environment.

[37] 3GPP TS 28.622 V15.2.0 (2018-12): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Generic Network Resource Model (NRM) Integration Reference Point (IRP); Information Service (IS) (Release 15).

[38] 3GPP TS 28.531 V16.1.0 (2019-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; Provisioning; (Release 16).

[39] 3GPP TS 28.554 V16.0.0 (2019-03): 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Management and orchestration; 5G end to end Key Performance Indicators (KPI) (Release 16).

[40] ITU-T Recommendation ITU-T L.1320 (03/2014): Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres.

[41] Smart-me - Smart energy solutions. Available: https://www.smartme.com/

[42] Recommendation ITU-R M.2083-0 (09/2015) IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond