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TECHNICAL SPECIFICATION

**Environmental Engineering (EE);
Measurement method for
energy efficiency of wireless access network equipment
Dynamic energy performance measurement method of 5G
Base Station (BS)**

Reference
DTS/EE-EEPS39

Keywords
5G, base station, energy efficiency, KPI, NR

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Modal verbs terminology

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Introduction

Increasing of energy consumption and the related cost has been one of the key questions among the whole industry depending on energy and specially in our context the telecom operators while energy consumption cost is one of the main contributors to their OPEX. Despite the increasing of the OPEX, the environmental aspect in terms of CO2 emission has been one of the most debated subjects within global warming discussions. Energy efficiency is one of the critical factors of the modern telecommunication systems.

In mobile telecom industry the energy consumption of the access network is the dominating part of the wireless telecom network energy consumption. Therefore, the core network and the service network are not considered in the present document. In a radio access network, the energy consumption of the Base Station is dominating.

In context of 5G, one is often talking about three classes of use cases: enhanced Mobile Broadband (eMBB), massive Machine-Type Communication (mMTC) and Ultra-Reliable and Low-Latency Communication (URLLC). eMBB corresponds to a more or less straightforward evolution of the mobile broadband services of today, enabling even larger data volumes and further enhanced user experience, higher end-user data rates while mMTC and URLLC correspond to services characterized by a massive number of devices and services with very low latency and extremely high reliability respectively.

The present document defines the dynamic measurement method for evaluation energy performance of 5G radio base stations with respect to only eMBB use case. Dynamic measurement method for evaluation energy performance of 5G radio base stations with respect to mMTC and URLLC is subjected for further study and will be handled in the later version of the present document. Due to the dynamic nature of eMBB service it may be very difficult or impossible to show gains of some Base Station features that improve energy efficiency using static method alone. Compared to static, dynamic method strives to give more realistic estimates of Base Station's energy consumption.

BS efficiency energy performance under dynamic traffic load conditions: the BS capacity under dynamic traffic load provided within a defined coverage area and the corresponding energy consumption are measured for given reference configurations.

1 Scope

The present document covers the following radio access technology:

- 5G NR

The methodology described in the present document is to measure base station dynamic energy performance. Within the present document, it is referred to dynamic measurement.

The results based on dynamic measurements of the BS provide energy performance information for BS with dynamic loads.

The present document covers only enhanced Mobile Broadband (eMBB) use case of 5G. Other use cases such as massive Machine-Type Communication (mMTC) and Ultra-Reliable and Low-Latency Communication (URLLC) will be subjected for future version of the present document.

Energy consumption of terminal (end-user) equipment is outside the scope of the present document however, how a user equipment (UE) affects a base station energy performance will be considered for further study.

The scope of the present document is not to define target values for the power consumption nor the energy performance of equipment.

The results should only be used to assess and compare the energy performance of complete base stations.

Wide Area Base Stations are covered in the present document.

2 References

2.1 Normative references

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

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

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

[1] ETSI EN 300 132-2: "Environmental Engineering (EE); Power supply interface at the input of Information and Communication Technology (ICT) equipment; Part 2: -48 V Direct Current (DC)".

[2] ETSI EN 300 132-1: "Environmental Engineering (EE); Power supply interface at the input to Information and Communication Technology (ICT) equipment; Part 1: Alternating Current (AC)".

[3] ETSI EN 300 132-3: "Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V".

[4] ETSI TS 138 211: "5G; NR; Physical channels and modulation (3GPP TS 38.211)".

[5] ETSI TS 138 104: "5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104)".

[6] ETSI TS 138 141-1: "5G; NR; Base Station (BS) conformance testing Part 1: Conducted conformance testing (3GPP TS 38.141-1)".

[7] IEC/ISO Guide 98-3 or equivalent GUM:2008/JCGM 100:2008: "Evaluation of measurement data - Guide to the expression of uncertainty in measurement".

NOTE: Available at http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf.

2.2 Informative references

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

[i.1] ISO/IEC 17025: "General requirements for the competence of testing and calibration laboratories".

[i.2] IEC 62018: "Power consumption of information technology equipment - Measurement methods".

NOTE: Equivalent to CENELEC EN 62018.

[i.3] ETSI ES 202 706-1: "Environmental Engineering (EE); Metrics and measurement method for energy efficiency of wireless access network equipment; Part 1: Power Consumption - Static Measurement Method".

[i.4] 3GPP TR 36.873: "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on 3D channel model for LTE".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

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

BS test control unit: unit which can be used to control and manage BS locally in a lab

busy hour load: period during which occurs the maximum total load in a given 24-hour period

distributed BS: BS architecture which contains remote radio heads (i.e. RRH) close to antenna element and a central element connecting BS to network infrastructure

efficiency: relation between the useful output (telecom service, etc.) and energy consumption of the BS

integrated BS: BS architecture in which all BS elements are located close to each other; for example, in one single cabinet

NOTE: The integrated BS architecture may include Tower Mount Amplifier (TMA) close to antenna.

low load: lowest generated traffic during the dynamic measurement period

medium load: medium load between the lowest and buy hour load generate during the dynamic measurement period.

power saving feature: software/hardware feature in a BS which contributes to decrease power consumption

static measurement: power consumption measurement performed with different radio resource configurations with pre-defined and fixed load levels (ETSI ES 202 706-1 [i.3])

UE group: group of UEs whose path losses to the BS are identical

Wide Area Base stations: Base Station characterized by requirements derived from Macro Cell scenarios with a BS to UE minimum coupling loss equals to 70 dB and having a rated output power (PRAT) above 38 dBm, where the Rated output power, PRAT, of the BS is the mean power level per carrier for BS operating in single carrier, multi-carrier, or carrier aggregation configurations that the manufacturer has declared to be available at the antenna connector during the transmitter ON period according to 3GPP standardization ETSI TS 138 104 [5] for NR

3.2 Symbols

Void.

3.3 Abbreviations

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

AC	Alternating Current
BS	Base Station
DC	Direct Current
DL	DownLink
DUT	Device Under Test
EC	Energy for Central part
ERRH	Energy for Remote Radio Part
GSM	Global System for Mobile communication
GUM	Guide to the expression of Uncertainty in Measurement
HW	HardWare
JCGM	Joint Committee for Guides in Metrology
KPI	Key Performance Indicator
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
NIST	National Institute of Standards and Technology
NR	New Radio
NSA	Non-StandAlone
OPEX	Operating Expense
PBCH	Packet Broadcast Control Channel
PCM	Pulse Code Modulation
PDF	Probability Density Function
PRB	Physical Resource Block
PSS	Primary Synchronizing Signal
RF	Radio Frequency
RMSI	Remaining Minimum System Information
RRH	Remote Radio Head
RX	Receiver
SA	StandAlone
SDH	Synchronous Digital Hierarchy
SIB	System Information Block
SS	Synchronization Signals
SSB	Synchronization Signal Block
SSS	Secondary Synchronizing Signal
SW	SoftWare
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TMA	Tower Mount Amplifier
TX	Transmitter
UE	User Equipment
UL	UpLink
URLLC	Ultra-Reliable Low-Latency Communication

4 Assessment method

The assessment method is covering the BS equipment dynamic efficiency for which the present document defines reference BS equipment configurations and reference load levels to be used when measuring BS efficiency.

The assessment procedure contains the following tasks:

1) Identification of equipment under test:

    1.1 Identify BS basic parameters (table A.1 in annex A).

    1.2 List BS configuration (annex B).

    1.3 List traffic load(s) for measurements (annex C).

    1.4 List of used power saving features and capacity enhancement features.

2) Efficiency measurement under dynamic load conditions, Measure BS equipment delivered task in terms of bits and the consumed energy under required conditions (see clause 6).

3) Collect and report the efficiency measurement results.

5 Reference configurations and Measurement conditions

5.1 Reference configurations

The BS equipment is a network component which serves a number of user equipment within a specific coverage area over an air interface. A BS interfaces user equipment (through air interface) and a wireless network infrastructure.

Reference configurations are defined annex B.

These configurations include integrated and distributed BS, mast head amplifiers, remote radio heads, RF feeder cables, number of carriers, number of sectors, power range per sector, frequency range, diversity, MIMO.

The BS shall be tested with its intended commercially available configuration at temperatures defined in clause 5.2.5. It shall be clearly reported in the measurement report if the BS cannot be operated without additional air-conditioning at the defined temperatures.

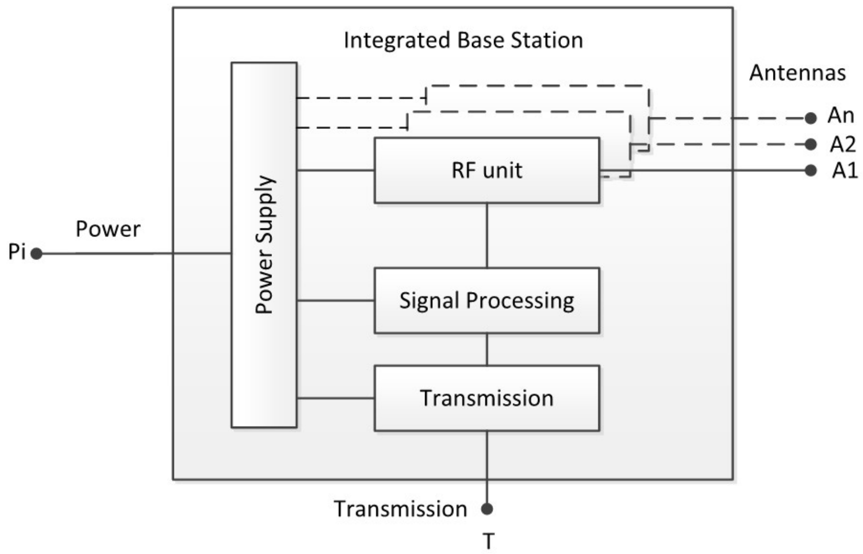


Figure 1: Integrated BS model (Example)

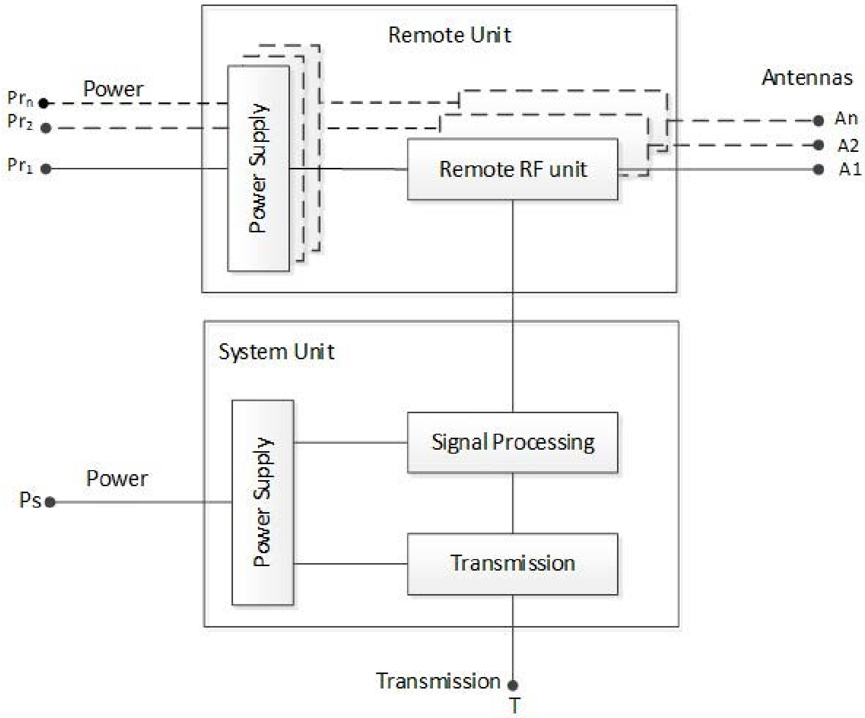


Figure 2: Distributed BS model (Example)

5.2 Measurement and test equipment requirements

5.2.1 Test equipment requirements

The measurement of the power consumption shall be performed by either measuring the power supply voltage and true effective current in parallel and calculate the resulting power consumption (applicable only for DC) or with a wattmeter (applicable for both AC and DC). The measurements can be performed by a variety of measurement equipment, including power clamps, or power supplies with in-built power measurement capability.

All measurement equipment shall be calibrated and shall have data output interface to allow long term data recording and calculation of the complete power consumption over a dedicated time.

The measurement equipment shall comply with following attributes:

- Input power:
  - Resolution: ≤ 10 mA; ≤ 100 mV; ≤ 100 mW.
  - DC current: ±1 %.
  - DC voltage: ±1 %.
  - AC power: ±1 %.
    - An available current crest factor of 5 or more.
    - The test instrument shall have a bandwidth of at least 1 kHz.

NOTE: Additional information on accuracy can be found in IEC 62018 [i.2].

- RF output power accuracy: ±0,4 dB.

5.2.2 BS Configuration

The BS shall be tested under normal test conditions according to the information accompanying the equipment. The BS, test configuration and mode of operation (baseband, control and RF part of the BS as well as the software and firmware) shall represent the normal intended use and shall be recorded in the test report.

The BS shall be tested with its typical configuration. In case of multiple configurations, a configuration with 3 sectors shall be used. Examples: a typical wide area BS configuration consists of three sectors and shall therefore be tested in a three-sector configuration.

If a BS is designed for dual or single sector applications, it shall be tested in its designed configuration.

The connection to the simulator via the BS controller interface shall be an electrical or optical cable-based interface (e.g. PCM, SDH, and Ethernet) which is commercially offered along with the applied BS configuration.

Additional power consuming features like battery loading shall be switched off.

The used power saving features and SW version shall be listed in the measurement report.

The measurement report shall mention the configuration of the BS for example the type of RF signal combining (antenna network combining, air combining or multi-carrier).

5.2.3 Transmit Signal and RF output power

The maximum RF transmit power that the base station under test is capable of shall be reported.

The base station under test shall control the RF transmit signal to fulfil the traffic profiles as listed in annex B.

The power amplifier(s) of the BS shall support the same crest factor (peak to average ratio) and back-off as applied in the commercial product.

All relevant requirements from 3GPP specifications for the 5G NR air-interface shall be fulfilled.

5.2.4 UE Emulator requirements and settings

UE power consumption is not considered in the present document. However, UE category and performance has a significant impact on the base station energy efficiency. To assess energy efficiency of the BS, the UE capabilities represented by the UE emulator shall be used as following.

- The UE emulator shall provide the total capacity (number of simultaneous UEs as defined in annex C, maximum data rate, etc.) to load the BS per the test specifications
- The UE emulator shall be capable of Supporting NR release 16
- Multiband radio interface support 400 MHz to 4 000 MHz
- Simulation capacity of 1 000 UE's
- Full stack E2E UE simulation
- Capability of Mobility simulation
- Fading simulation capability (according 3GPP models)
- Possibility to control every UE position (pathloss), data traffic, fading etc. individually
- Logging of UE performance

The used UE emulator type shall be recorded in detail for the test protocol. This shall include HW and S/W versions.

5.2.5 Environmental conditions

For the BS efficiency measurements, the environmental conditions under which the BS shall be tested are defined as follows.

Table 1: BS environmental conditions

Condition	Minimum	Maximum
Barometric pressure	86 kPa (860 mbar)	106 kPa (1 060 mbar)
Relative Humidity	20 %	85 %
Vibration	Negligible	
Temperature	+25 °C	
Temperature accuracy	±2 °C	

The BS efficiency measurements shall be performed when stable temperature conditions inside the equipment are reached. For this purpose, the BS shall be placed in the environmental conditions for minimum two hours with a minimum operation time of one hour before doing the measurements. After change of traffic load, a minimum operation time of one hour shall also be applied before conducting measurements again.

5.2.6 Power supply

For the measurements, the following operating voltage values shall be used. Equipment designed for non-standard power supply voltages shall use the nominal equipment operating voltage (±2,5 % tolerance).

Nominal values and operating values shall be according to table 2 and the related ETSI standards.

Table 2: Operating voltages during testing

Supply type	Nominal value	Operating value during testing	Related standards
AC (230 V)	230 V	230 V (±2,5 %)	ETSI EN 300 132-1 [2]
DC (-48 V)	-48 V	-54,5 V (±2,5 %)	ETSI EN 300 132-2 [1]
DC (400 V)	Max. 400 V	380 V (±2,5 %)	ETSI EN 300 132-3 [3]

6 Energy performance measurement

6.1 General

This clause describes the method to measure the equipment performance considering the existing standards as listed in clause 2. It also gives the conditions under which these measurements shall be performed.

6.2 Energy efficiency performance KPI Definition

For dynamic measurement, the BS shall be operated in a test and measuring environment as illustrated in figure 3.

For equipment efficiency measurements the following items are specified for each system in annexes B and C:

- Reference configuration (annex B).
- Frequency bands (annex B).
- Traffic load levels (annex C).
- Traffic case (annex C).

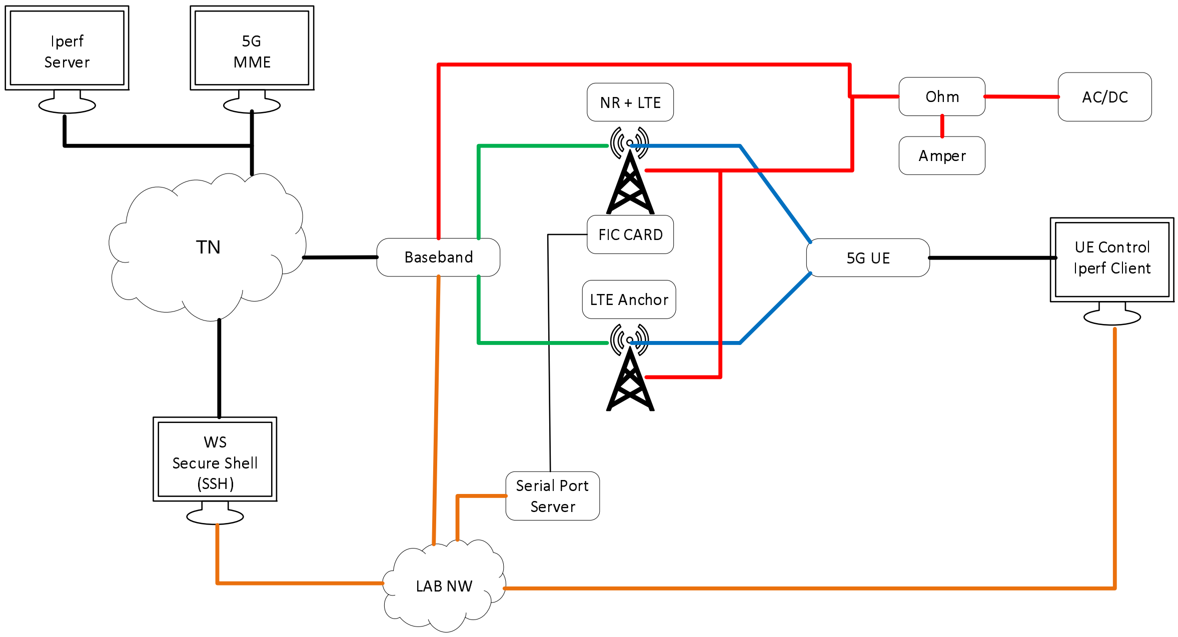
Power Savings features and other radio and traffic related features implemented in BS can be used during the testing. Such features shall be listed in the measurement report.

The BS is powered by a DC or AC power supply. The control unit itself is connected to the core network. The core network can be either a real network element or a core network emulator.

6.3 Energy efficiency performance measurement

6.3.1 Measurement lab setup

Figure 3 shows the test setup using a UE emulator and a channel emulator connected to the BS under test. A traffic generator is used to generate both data traffic requested by the UEs and measuring the received data by the UEs during the measurement period. The test setup in figure 3 is applicable for 5G NR and LTE as an anchor, None Stand Alone (NSA) but it can also be applicable for only NR, Stand Alone (SA) case by just removing the LTE Anchor from the test setup.



NOTE: BS as defined in figure 1 (integrated BS) or figure 2 (distributed BS). AC supply to be used for BS with build in AC power supply, otherwise default DC supply voltage as specified in clause 5.2.5.

Figure 3: Example of NSA test setup for dynamic measurement with integrated BS and UE emulator

The BS shall be operated and controlled via the controller units as illustrated in figure 3 in conjunction with the UE distribution and the traffic models and reference parameters given in annexes B and C.

A channel emulator is used either by an in-build channel emulator in the UE emulator or as a standalone channel emulator. It is used for emulating fading over the radio channels between UEs and the BS. The fading models should be according the models specified in 3GPP TR 36.873 [i.4].

6.3.2 UE distribution

The UEs are distributed in three different path loss regions, low path loss, medium path loss and high path loss regions. The number of allocated UEs in each region are according to annex C. The path loss value for each region is also according to annex C.

The number of UEs for low, medium, and busy-hour traffic loads are different and are according to annex C.

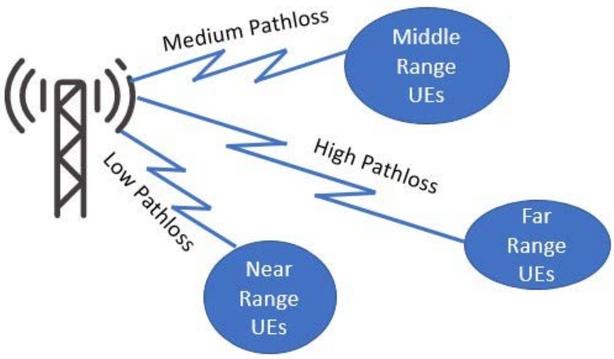


Figure 4: UE distribution in three different pathloss regions

6.3.3 Data traffic model

The traffic model used for BS energy efficiency measurement in the present document is based on artificially generated data traffic by a traffic generator. This traffic generator is either inbuild in the UE emulator used in the test setup or is a standalone traffic generator. The following requirements shall be fulfilled for the data traffic model in the present document.

- The data traffic model shall be based on TCP protocol.
- Measurement results shall be repeatable within a given confidence interval of 95 %.
- The total number of delivered files, file types and data volume per UE is defined in annex C.
- An interarrival time shall be applied before requesting a new file by each UE. When this time is elapsed, a UE will request the next file. This time could be different for different UE's, load scenarios and file sizes and is defined in annex C.
- An idle state time shall be applied when all the UEs have finished requesting data and the BS enters the idle state. This idle state time is defined according to annex C.
- Startup procedure: In order to reduce the time to reach stable conditions, it is recommended that each emulated UE shall start requesting files individually, with a start-up delay between each UE file request start.

Figure 5 shows a sketch over how different files in a random way are transmitted to each UE. At the start of the test each UE starts to be connected randomly and independent of each other (No UE starts at the same time). The data traffic model used in the present document is based on transmitting three different file sizes denoted as small, medium, and large file size. The size of these files is defined in annex C. The number of files to be requested by each UE is fixed and is different for small, medium, and large file size which are specified in annex C.

During the measurement, each UE starts requesting a predefined fixed number of files from a bucket of files assigned to this UE. The number of these files are defined in annex C and are denoted as "S" for small files, "M" for medium files and "L" for large files. Each UE continues requesting files until there is no file left to be requested in the bucket assigned to this UE.

When there is no file left to be sent by BS to the UEs i.e. all the files have been requested and received by the UEs, the BS enters an idle state for a specific idle time according to annex C.

After this idle time has been elapsed the measurement will be stopped and the energy consumption, the received data by the UEs and the total measurement time will be collected.

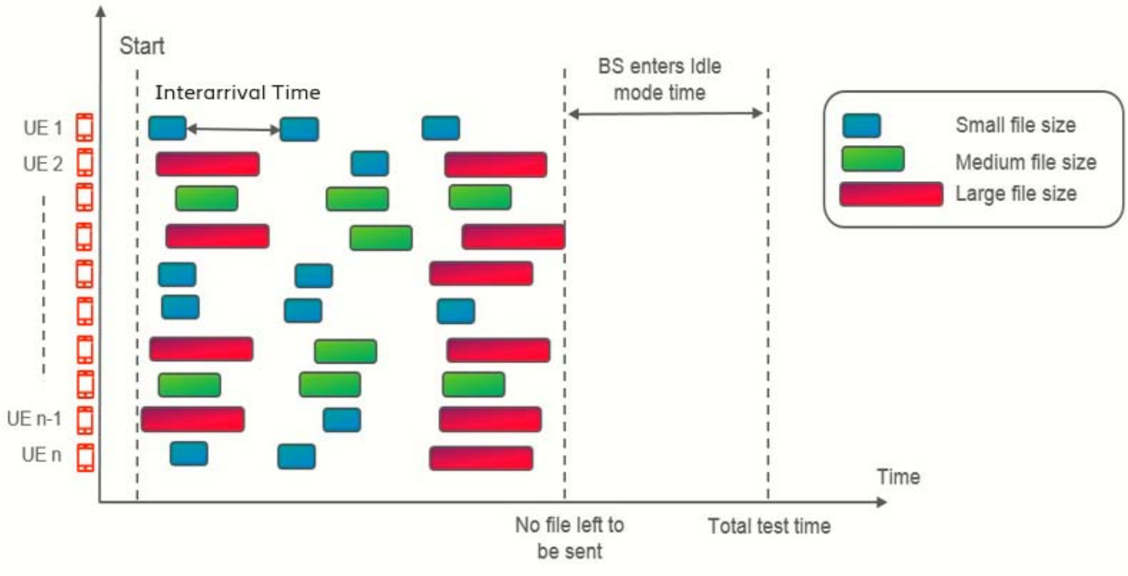


Figure 5: Data traffic flow to each UE

6.3.4 Measurement Time Definition

The total measurement time is dependent on the time when all UEs have received their requested files sent by the base station plus the idle sate time of the BS. This measurement time is denoted as $T_{measurement}$ and it is the time between the start of the measurement and the time when the measurement has stopped.

The measured time for low, medium and busy-hour traffic loads are: $T_{measurement\text{-}low}$, $T_{measurement\text{-}medium}$, and $T_{measurement\text{-}busy\text{-}hour}$ respectively.

6.3.5 Low traffic model

For low load traffic level, the number of used UEs is at the low level. Time between requesting each file by each UE, file sizes and file count is specified in annex C.

6.3.6 Medium traffic model

For medium load traffic level, the number of UEs is at the medium level. Time between requesting each file by each UE, file sizes and file count is defined in annex C.

6.3.7 Busy-hour traffic model

For the busy-hour traffic level the number of used UEs is at the high level. Time between requesting each file by each UE, file sizes and file count is defined in annex C.

6.3.8 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 clause 6.3.3 and annex C. 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.

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:

$$DV_{total} = \left(DV_{low} \times \frac{W_{low}}{T_{measurement\ low}}\right) + \left(DV_{medium} \times \frac{W_{medium}}{T_{measurement\ medium}}\right) + \left(DV_{busy\ hour} \times \frac{W_{busy\ hour}}{T_{measurement\ busy\ hour}}\right)\ [bits] \quad (1)$$

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

6.3.9 Power and Energy Consumption Measurement

The energy consumption measurements shall be performed when the stable temperature conditions inside the equipment are reached. For this purpose, the BS shall be placed in the environmental conditions for minimum two hours with a minimum operation time of one hour before starting the measurements. After change of traffic load, a minimum operation time of one hour shall also be applied before conducting measurements again.

Measurement results shall be captured earliest when the equipment including the selected load is in stable operating conditions.

The RF output powers as well as the corresponding power consumptions of the BS shall be measured and collected during the whole measurement period according to the traffic model described in clause 6.3.3 and annex C.

The test models as well as the different traffic loads are defined in clause 6.3.3 and annex C.

The power consumption of the BS shall be given in Watts in accordance with the accuracies and the resolutions given in clause 5.2.5.

The measurement expanded uncertainty shall be assessed according to annex D.

6.3.10 Energy Consumption 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, $P_{i,equipment}^{traffic\_scenario}$ is the measured power value for the i^{th} sampled measurement during the measurement period. The energy $E_{equipment}^{traffic\_scenario}$ which is the energy consumption of the BS during the measurement is calculated as follows:

$$E_{equipment}^{traffic\_scenario\_x} = \sum_{k=1}^{n}\left(\Delta t_m \cdot P_{k,equipment}^{traffic\_scenario\_x}\right) \quad [Wh] \quad (2)$$

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

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

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

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

$$E_{total\ equipment} = \left(E_{low} \times \frac{W_{low}}{T_{measurement\ low}}\right) + \left(E_{medium} \times \frac{W_{medium}}{T_{measurement\ medium}}\right) + \left(E_{busy\ hour} \times \frac{W_{busy\ hour}}{T_{measurement\ busy\ hour}}\right) [Wh] \quad (5)$$

For calculation of the total energy consumption for distributed BS similar calculation as above for both radio remote part and the central equipment part and then summing up these two parts to obtain the total energy consumption for a distributed BS.

6.3.11 Base Station Energy Efficiency KPI

The base station energy efficiency KPI is an indicator for showing how energy efficient a base station is for doing a work. This work in the present document is defined as delivered useful bits to UEs covered by this base station. A base station is more energy efficient when doing more work with same energy, doing 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 and is consisting of delivered useful bits in the numerator and consumed energy in the denominator.

$$BSEP = \frac{DV_{total}}{E_{equipment}^{total}} \left[\frac{bits}{Wh}\right] \quad (6)$$

Where DV_{total} is the total delivered bits during the measurement for all three traffic levels according to clause 6.3.8 and $E_{equipment}^{total}$ is the total consumed energy during the measurement period for delivering DV_{total} according to clause 6.3.10.

6.3.12 UE quality of service KPI

The final report shall include UE quality of service KPI as throughput. For every transmitted file an average throughput for that file shall be calculated. Average throughput of a file is calculated as file size divided by file transmission time. Transmission time starts at when a UE requests a file and ends when the complete files is received.

For each load level average UE throughput shall be reported for all UEs. 95 % percentile shall also be provided, annex A.

7 Uncertainty

The measurement expanded uncertainty shall be assessed according to annex D.

8 Measurement report

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

A list of reference parameters, measurement conditions, test results, **uncertainty analysis** (see annex D) and derived calculation results which shall be reported according to annex A. The report shall contain a full list of equipment, interfaces and detailed of test setup realized to perform the measurement in line with figure 3.

Further guidelines on the test report can be found in clause 5.10 of ISO/IEC 17025 [i.1].

Annex A (normative): Test Reports

A.1 General information to be reported

Table A.1: Test general information

Items	Remarks
1) Test report reference and version	
2) Date of the test	
3) Standard Used as test methodology	
4) Location of the test	
5) Name of test organization and responsible person	
6) Tested equipment	
6.1) Tested HW unit names and serial numbers	
6.2) Software version of tested equipment	
7) List of used measurements equipment including type, serial number and calibration information	

Table A.2: BS reference parameters to be reported

Parameter	Value	Unit
1) BS configuration		
1.1) Number of sectors		
1.2) Nominal max RF output power per sector		W
1.3) Number of Carriers per sector		
1.3.1) Number of carriers the BS is able to support		
1.3.2) Number of carriers, for which the HW was enabled (independent whether or not the carriers were used for the test)		
1.3.3) Number of carriers used during the test		
1.4) TX diversity		
1.5) RX diversity (number)		
1.6) Type of RF signal combining		
1.7) Remote Radio Head (Yes/No)		
2) Frequency		
2.1) Downlink band		MHz
2.2) Uplink band		MHz
2.3) Channel bandwidth		MHz
2.4) Sub-carrier spacing		kHz
3) Environment		
3.1) Temperature range		°C
3.2) Type of air filter		
4) Features		
4.1) Power saving features		
4.2) Coverage and capacity features		
4.3) Downlink ciphering used? (Y/N)		

A.2 Base Station Energy Performance report

Table A.3: Measurements conditions and results to be reported for BS Energy Performance

Parameter	Test case 25 °C	Unit
1) Test environment		
1.1) Temperature during test (measured)		°C
1.2) Pressure (measured)		kPa
1.3) Relative humidity (measured)		%
2) Frequency used at test		
2.1) Downlink Centre frequency of middle channel		MHz
2.2) Uplink Centre frequency of middle channel		MHz
3) Supply voltage		
3.1) DC voltage (measured)		V
3.2) AC voltage (measured, phase to neutral)		V
3.3) AC Frequency (measured)		Hz
4) Weighting Factors		
4.1) W_{low}		hour
4.2) W_{medium}		hour
4.3) $W_{busy\text{-}hour}$		hour
5) Dynamic energy consumption (measured)		
5.1) Low traffic level		Wh
5.2) Medium traffic level		Wh
5.3) Busy-hour traffic level		Wh
6) Accumulated measured data volume		
6.1) Low traffic level		bits
6.2) Medium traffic level		bits
6.3) Busy-hour traffic level		bits

Table A.4: Calculated results to be reported for BS Energy Performance

Parameter	Value	Unit
1) Total delivered data in bits during the test		bits
2) Total energy consumption		Wh
3) Coverage		km^2
4) Base Station Energy Performance (BSEP)		bits/Wh
5) PRB Utilization		
5.1) Low load PRB Utilization		%
5.2) Medium load PRB Utilization		%
5.3) Busy-hour load PRB Utilization		%
6) Average UE throughput		kbps
7) Expanded uncertainty		%

The measurement report shall include the uncertainty table following the template defined in table D.1.

Table A.5: UE Emulator reporting table

Item	Value	Remarks	Unit
Additional Antenna attenuator for DL test		Value of sensitivity and power correction attenuators as specified in section UE requirements	dB
Additional Antenna attenuator for UL test		Value of sensitivity and power correction attenuators as specified in section UE requirements	dB
UE category	4	This category is fixed for purpose of testing	
UE emulator version			
UE emulator model			
UE manufacturer			
Maximum specified DL data rate		According to manufacturer data sheet	kbps
Maximum specified UL data rate		According to manufacturer data sheet	kbps
Serial number			
UE emulator SW version			
Other		Any other information/parameter that is needed to reproduce the measurement shall be stated	

Annex B (normative): Reference parameters for NR system

Reference configurations for NR shall be:

- Only normal cyclic prefix is used.
- SS block (PBCH, PSS and SSS) shall be transmitted with a periodicity of 20 ms and a number of SS blocks per SSB set according to table B.1. SS block placement in the frequency domain can be freely selected according to the allowed synchronization rasters in ETSI TS 138 211 [4].
- RMSI (SIB 1) shall be transmitted with a repetition periodicity of 20 ms.
- RF output power level:
  - Power Range applicable to the "Wide Area BS" classes as defined in ETSI TS 138 104 [5].
  - Maximum nominal RF output power at reference point (antenna connector for BS type 1-C, TAB connector for BS type 1-H) according to product specification and according to the load levels (Output power at reference point = load model based percentage × Maximum nominal RF output power) measured at the reference point according to ETSI TS 138 141-1 [6].
- Power Input:
  - -48 V DC, 230 V AC, 400 V DC.

Table B.1: Maximum allowed number of SS block and SSB set configurations

Frequency range	FR1 < 3 GHz	3 GHz < FR1 < 6 GHz
SS blocks per SSB set	4	8
SSB set periodicity [ms]	20	20

Downlink and uplink settings for NR TDD:

As specified for NR-FR1-TM1.1 in ETSI TS 138 141-1 [6] for FR1.

Annex C (normative): Data Traffic Model

C.1. Data Traffic Model

The UEs shall be distributed based on the path loss distribution according to tables C.2, C.3 and C.4 for low, medium and busy-hour traffic model. Three file sizes are requested by UEs. These three files are different for different traffic load levels according to tables C.2, C.3 and C.4. There is a time applied between each requested file by UEs. This inter arrival time is different for different file sizes and ae depicted in tables C.2, C.3 and C.4.

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. It is up to the operator to define the weighting factors that matching the load distribution profile in its network. Note that the selected weighting factors shall sum up to 24 hours.

In case no weighting factors has been defined by the operator, the default values in table C.1 can be used.

In addition to the path loss settings the minimum power received by the UE shall be specified.

Table C.1: PRB Utilization, Total number of UEs and Weighting factor for 100 MHz bandwidth

Traffic load level	Low	Medium	Busy-hour
Total number UEs	72	96	160
Default Weighting Factor [hour]	$W_{low} = 6$	$W_{Medium} = 10$	$W_{busy-hour} = 8$

Table C.2: Traffic model parameters for Low Load level

Low Load Level									
Path loss [dB]	85			110			130		
File size [kByte]	0,1	1	250	0,1	1	250	0,1	1	250
% of file distribution	50 %	22 %	28 %	50 %	22 %	28 %	50 %	22 %	28 %
Inter Arrival Time [ms]	4	20	200	4	20	200	4	20	200
# UEs per files size	4	4	4	28	8	8	4	4	4
# UEs per path loss	12			48			12		
% of UEs per path loss	17 %			66 %			17 %		

Table C.3: Traffic model parameters for Medium Load Level

Medium Load Level									
Path loss [dB]	85			110			130		
File size [kByte]	0,1	1	250	0,1	1	250	0,1	1	250
% of file distribution	50 %	25 %	25 %	50 %	25 %	25 %	50 %	25 %	25 %
Inter arrival time [ms]	4	20	200	4	20	200	4	20	200
# UEs per path files size	4	4	4	40	16	16	4	4	4
# UEs per path loss	12			72			12		
% of UEs per path loss	12,5 %			75 %			12,5 %		

Table C.4: Traffic model parameters for Busy-hour Load Level

Busy-hour Load Level									
Path loss [dB]	85			110			130		
File size [kByte]	0,1	1	250	0,1	1	250	0,1	1	250
% of file distribution	44 %	28 %	28 %	50 %	25 %	25 %	50 %	25 %	25 %
Inter arrival time [ms]	4	20	200	4	20	200	4	20	200
# UEs per path files size	8	8	8	56	28	28	8	8	8
# UEs per path loss	24			112			24		
% of UEs per path loss	15 %			70 %			15 %		

C.2 Measured data for BS Energy Performance KPI calculation

To calculate the BS Energy Performance KPI, the equation (6) specified in clause 6.3.11 shall be applied. Table C.5 gives data needed for calculation the BS EE KPI.

Table C.5: Data required for calculation of BSEP

	Low load traffic	Medium load traffic	Busy-hour load traffic
Weighting factor label	W_{low}	W_{medium}	$W_{busy-hour}$
Measured time	$T_{measured-low}$	$T_{measured-medium}$	$T_{measured-busy-hour}$
Measured data volume [bits]	$DV_{measured-low}$	$DV_{measured-medium}$	$DV_{measured-busy-hour}$
Measured Energy Consumption [Wh]	$E_{equipment}^{measured-traffic\_scanrio\_low}$	$E_{equipment}^{measured-traffic\_scanrio\_medium}$	$E_{equipment}^{measured-traffic\_scanrio\_busy\_hour}$

Annex D (normative): Uncertainty assessment

D.1 General requirements

The wireless network efficiency data produced by the methods detailed in the present document will be subject to uncertainty due to the tolerance of measurement procedures or variance of real installations to the standard models suggested. The uncertainty of the measured parameters can be evaluated and will therefore provide comparable data, whilst that of the models used is subjective and should be assigned a sensitivity to assess significance.

The assessment of uncertainty in the measurement of the dynamic efficiency of a base station shall be based on the general rules provided by the IEC/ISO Guide 98-3: 2008 or equivalent GUM:2008 [7] available at:

- http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf.

Uncertainty factors are grouped into two categories according to the method used to estimate their numerical value:

- Type A: Those which are evaluated by statistical means.
- Type B: Those which are evaluated by other means, usually by scientific judgment using information available.

When a Type A analysis is performed, the standard uncertainty u_i shall be derived from the estimate from statistical observations.

When Type B analysis is performed, the standard uncertainty u_i is derived from the parameter $a = (a_+ - a_-)/2$, where a_+ is the upper limit and a_- is the lower limit of the measured quantity, and taking into account the distribution law of measured quantity, as follows:

- Normal law: $u_i = a/k$ where k is a coverage factor.
- U-shaped (asymmetric) law: $u_i = a/\sqrt{2}$.
- Rectangular law: $u_i = a/\sqrt{3}$ (default value to be used in the absence of any other information).
- Triangular law: $u_i = a/\sqrt{6}$ (not used in the present document).

D.2 Components contributing to uncertainty

D.2.1 Contribution of the measurement system

D.2.1.1 Uncertainty Tree description

The factors contributing to uncertainty are schematically shown in the uncertainty tries (figure D.1).

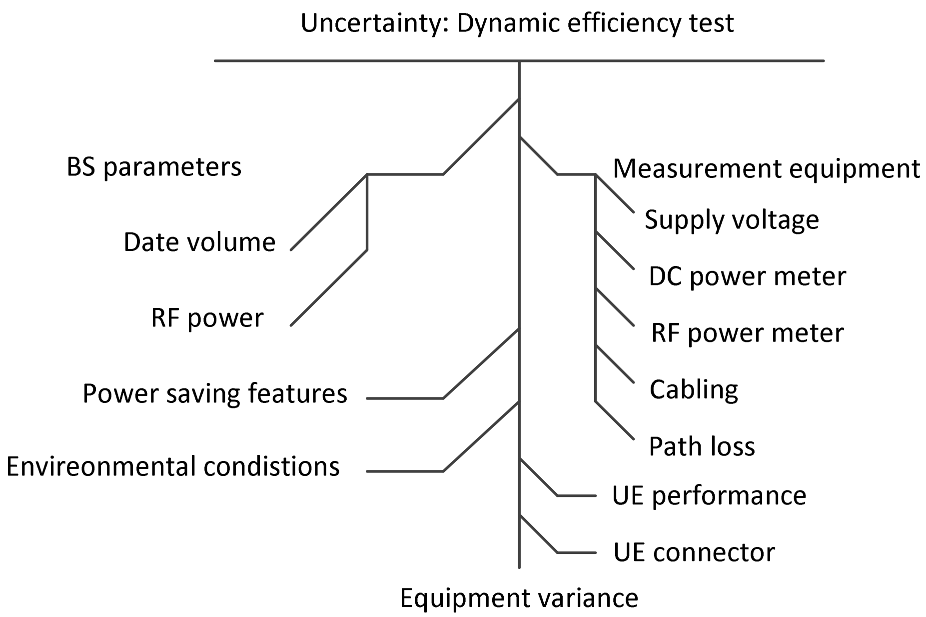


Figure D.1: Uncertainty tree - dynamic efficiency test

D.2.1.2 Measurement equipment (dynamic)

The uncertainty contributed by the measurement equipment, e.g. voltmeter, power meter, RF power meter shall be assessed with reference to its calibration certificates. The uncertainty due to the measurement device shall be evaluated assuming a type B normal probability distribution.

D.2.1.3 Attenuators, cables (dynamic)

The uncertainty contributed by the attenuator, shall be assessed with reference to its calibration certificates. The uncertainty due to the attenuator shall be evaluated assuming a Type B normal probability distribution.

D.2.1.4 UE emulator (dynamic)

The uncertainty contributed by the UE emulator, shall be assessed with reference to its calibration certificates. The uncertainty due to the UE emulator shall be evaluated assuming a Type B normal probability distribution.

D.2.2 Contribution of physical parameters

D.2.2.1 Impact of environmental parameters (dynamic)

The impact of environmental parameters (mainly temperature) is assessed considering temperature variation during the measurement period. It has to be assured that the DUT has reached stable conditions as defined in clause 5.2.5. The uncertainty shall be evaluated assuming a Type B rectangular probability distribution.

D.2.2.2 Impact of path loss(dynamic)

The contribution due to the path loss, radio effects, etc are controlled during the tests and the resulting error is less than ± x %. The uncertainty shall be evaluated assuming a Type B rectangular probability distribution. Path loss uncertainty is a result of attenuator and cable uncertainty as described under clause D.2.1.3.

D.2.2.3 Data volume (dynamic)

The uncertainty contributed by the traffic monitoring, shall be assessed with reference to its calibration certificates. The uncertainty due to the traffic monitoring shall be evaluated assuming a Type B normal probability distribution.

D.2.3 Variance of device under test

Based on component variances the individual base stations will have a certain deviation from the nominal value. The tested base station shall represent the nominal performance. The product to product efficiency spread is not considered in this uncertainty analysis but additional results on product efficiency spread might be provided.

D.3 Uncertainty assessment

D.3.1 Combined and expanded uncertainties

The contributions of each component of uncertainty shall be registered with their name, probability distribution, sensitivity coefficient and uncertainty value. The results shall be recorded in a table of the following form. The combined uncertainty shall then be evaluated according to the following formula:

$$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2} \tag{D.1}$$

where c_i is the weighting coefficient.

The expanded uncertainty shall be evaluated using a confidence interval of 95 % using the templates defined in table D.1 for dynamic measurements.

Table D.1: Uncertainty analysis for dynamic efficiency assessment

ERROR SOURCES	Description (clause)	Uncertainty Value (%)	Probability Distribution	Divisor	c_i	Standard Uncertainty (%)
Measurement Equipment						
Supply voltage	D.2.1.1		Normal	1	1	
Power consumption / DC power meter	D.2.1.1		Normal	1	1	
RF power / RF power meter	D.2.1.1		Normal	1	1	
Cabling, Attenuators	D.2.1.3		Normal	1	1	
Data volume	D.2.2.3		Normal	1	1	
User equipment	D.2.1.4		Rectangular	$\sqrt{3}$	1	
Physical Parameters						
Environment conditions (T)	D.2.2.1	5 %	Rectangular	$\sqrt{3}$	0,5	
Impact of path loss	D.2.2.3		xx	xx	xx	
BS parameters			n/a			
Equipment variance	D.2.3	-	Gaussian			
Combined standard uncertainty			$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2}$			
Expanded uncertainty (confidence interval of 95 %)			Normal			$u_e = 1{,}96\, u_c$

D.3.2 Cross correlation of uncertainty factors

Cross correlations of above uncertainty factors are not considered if not otherwise stated.

D.3.3 Maximum expanded uncertainty

The expanded uncertainty with a confidence interval of 95 % shall not exceed 20 % for dynamic tests.

If the expanded uncertainty is exceeding this target, then the uncertainty shall be added to the measured results.

Annex E (informative): Bibliography

- NIST Technical Note 1297: "Guidance for evaluating and expressing the uncertainty of NIST measurement results".

History

Document history		
V1.1.1	December 2020	Publication