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Measurement method for energy efficiency of network functions virtualization

Recommendation ITU-T L.1361

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ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.1361

Measurement method for energy efficiency of network functions virtualization

Summary

Recommendation ITU-T L.1361 is intended to define common energy efficiency measurement methods for network functions virtualization (NFV) environments, it does not try to cover all of the different types of VNFs (e.g., firewall, gateway, etc.), but it provides the basis to make an extensible definition.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

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Introduction

Network functions virtualization (NFV) changes the traditional telecom network architecture by replacing physical equipment with network functions running on a standard server platform. Three main domains are identified in high-level NFV architecture. The virtualized network functions (VNFs) are the software implementations of network functions which run over the NFV infrastructure (NFVI). NFVI includes any physical and virtualized resources for supporting the execution of the VNFs. NFV management and orchestration (MANO) covers the orchestration and lifecycle management of physical and/or software resources that support the infrastructure virtualization and the lifecycle management of VNF itself. The three decoupled elements, connected through standardized and open interfaces, can be provided by different vendors. VNFs and NFVI are the dominant parts from an energy consumption point of view.

Recommendation ITU-T L.1361

Measurement method for energy efficiency of network functions virtualization

1 Scope

This Recommendation defines the metrics and measurement methods for the evaluation of the energy efficiency of functional components of a network functions virtualization (NFV) environment. Figure 1 shows the NFV function components in the scope of this Recommendation. The NFV functional components include virtual network functions (VNFs) and NFV infrastructure (NFVI) defined in the NFV architecture framework as described in [b-ETSI GS NFV 002]. Management and orchestration (MANO) is not included in the system under test, but will be eventually used as a test environment.

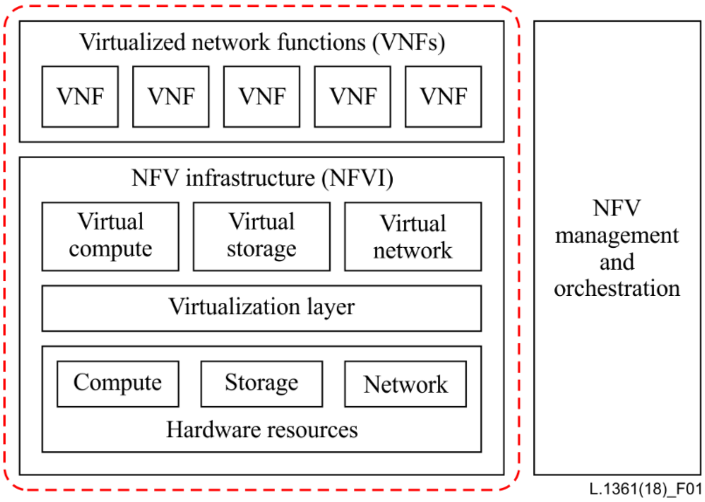

Figure 1 – NFV function components

The measurement method described in the present Recommendation is intend to be used to assess and compare the energy efficiency of single functional components independently in both laboratory testing and pre-deployment testing. Energy efficiency of co-located VNFs sharing same platform resources cannot be compared by using the method defined in the present Recommendation. The scope of this Recommendation is not to define the measurement method in an operational NFV environment.

The present Recommendation is intended to define common energy efficiency measurement methods for NFV environments and not try to cover all different types of VNFs (e.g., firewall, gateway, etc.), but it does provide the basis to make an extensible definition.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1200] Recommendation ITU-T L.1200 (2012), *Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment.*

[ITU-T L.1315] Recommendation ITU-T L.1315 (2017), *Standardization terms and trends in energy efficiency*.

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

[ETSI EN 300 132-2] ETSI EN 300 132-2 V2.5.1 (2016), *Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment – Part 2: Operated by -48 V direct current (dc).*

[ETSI GS NFV-TST 008] ETSI GS NFV-TST 008 V3.3.1 (2018), *Network Functions Virtualisation (NFV) Release 3; Testing; NFVI Compute and Network Metrics Specification.*

[ETSI GS NFV-IFA 027] ETSI GS NFV-IFA 027 V2.4.1 (2018), *Network Functions Virtualisation (NFV) Release 2; Management and Orchestration; Performance Measurements Specification.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 network function [ETSI GS NFV 003]: Functional block within a network infrastructure that has well-defined external interfaces and well-defined functional behaviour.

NOTE – In practical terms, a Network Function is today often a network node or physical appliance.

3.1.2 network functions virtualization (NFV) [ETSI GS NFV 003]: Principle of separating network functions from the hardware they run on by using virtual hardware abstraction.

3.1.3 network functions virtualization infrastructure (NFVI) [ETSI GS NFV 003]: Totality of all hardware and software components that build up the environment in which VNFs are deployed.

NOTE – The NFVinfrastructure can span across several locations, e.g., places where data centres are operated. The network providing connectivity between these locations is regarded to be part of the NFV infrastructure. NFVinfrastructure and VNF are the top-level conceptual entities in the scope of network function virtualization. All other components are sub-entities of these two main entities.

3.1.4 network service [ETSI GS NFV 003]: composition of network function(s) and/or network service(s), defined by its functional and behavioural specification.

NOTE – The network service contributes to the behaviour of the higher layer service, which is characterized by at least performance, dependability, and security specifications. The end-to-end network service behaviour is the result of the combination of the individual network function behaviours as well as the behaviours of the network infrastructure composition mechanism.

3.1.5 physical network function (PNF) [ETSI GS NFV 003]: Implementation of an NF via a tightly coupled software and hardware system.

3.1.6 virtualized network function (VNF) [ETSI GS NFV 003]: Implementation of an NF that can be deployed on a network function virtualization infrastructure (NFVI).

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 system under test: One or more function components of NFV being measured.

3.2.2 useful output: Maximum capacity of the system under test which is depending on the different functions. For additional details, see [ITU-T L.1315].

NOTE – Useful output is expressed as the number of Erlang (Erl), Packets/s (PPS), Subscribers (Sub), or simultaneously attached users (SAU).

3.2.3 energy consumption: Amount of consumed energy.

NOTE – Energy consumption is measured in Joules or kWh (where 1 kWh = 3.6×10^6 J) and corresponds to energy use.

3.2.4 energy efficiency: Relation between the useful output and energy consumption.

3.2.5 erlang: Average number of concurrent calls carried by the circuits.

3.2.6 function: Logical representation of a network element defined by 3GPP.

3.2.7 node: Physical representation of one or more functions.

3.2.8 power consumption: Amount of consumed power.

NOTE – Power consumption is measured in W and corresponds to the rate which energy is converted.

3.2.9 resource consumption: Virtual machine (VM) resources, virtual network (VN) resources.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CPU	Central Processing Unit
EER	Energy Efficiency Ratio
HSS	Home Subscriber Server
HW	Hardware
KPI	Key Performance Indicator
NF	Network Function
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NSB	Network Service Benchmarking
MANO	Management and Orchestration
PNF	Physical Network Function
QoS	Quality of Service
RER	Resource Efficiency Ratio
SAU	Simultaneously Attached Users
SLA	Service Level Agreement
SPEC	Standard Performance Evaluation Corporation
SUT	System Under Test
SW	Software
VM	Virtual Machine
VN	Virtual Network
VNF	Virtualized Network Function
VNFC	VNF Component

5 Conventions

None.

6 Metrics definition

6.1 Overview of system under test

In traditional networks, physical network elements provide network functions as a combination of vendor specific hardware and software. The system under test (SUT) is a physical network element which is usually taken as a "black box" in energy efficiency measurement standards. But in a NFV environment, the functionality of the physical network element is decoupled into software and hardware via virtualization. Network functions are executed as VNFs on a NFVI composed by general purpose computing, networking and storage hardware resources and a virtualization layer. All of them are managed and orchestrated by MANO. There will be many potential suppliers for NFV sub-systems and components, which need to be measured separately for what concerns the energy efficiency performance.

The energy efficiency metrics are typically defined as a functional unit of useful output divided by the energy consumption. As shown in Figure 2, NFV architecture decomposes the integrity of traditional energy efficiency measurement which tightly connects useful service output to energy consumption. VNF is the software implementation of a network function which consumes resources provided by a NFVI, to produce service capacity to cloud service users. The NFVI consumes energy to provide infrastructure resources to support the execution of the VNF. Such decoupled architecture introduces complexity to the measurement process. Resource consumption should be monitored, the internal configuration of the SUT and test environment must be specified and reported to ensure repeatability and comparability.

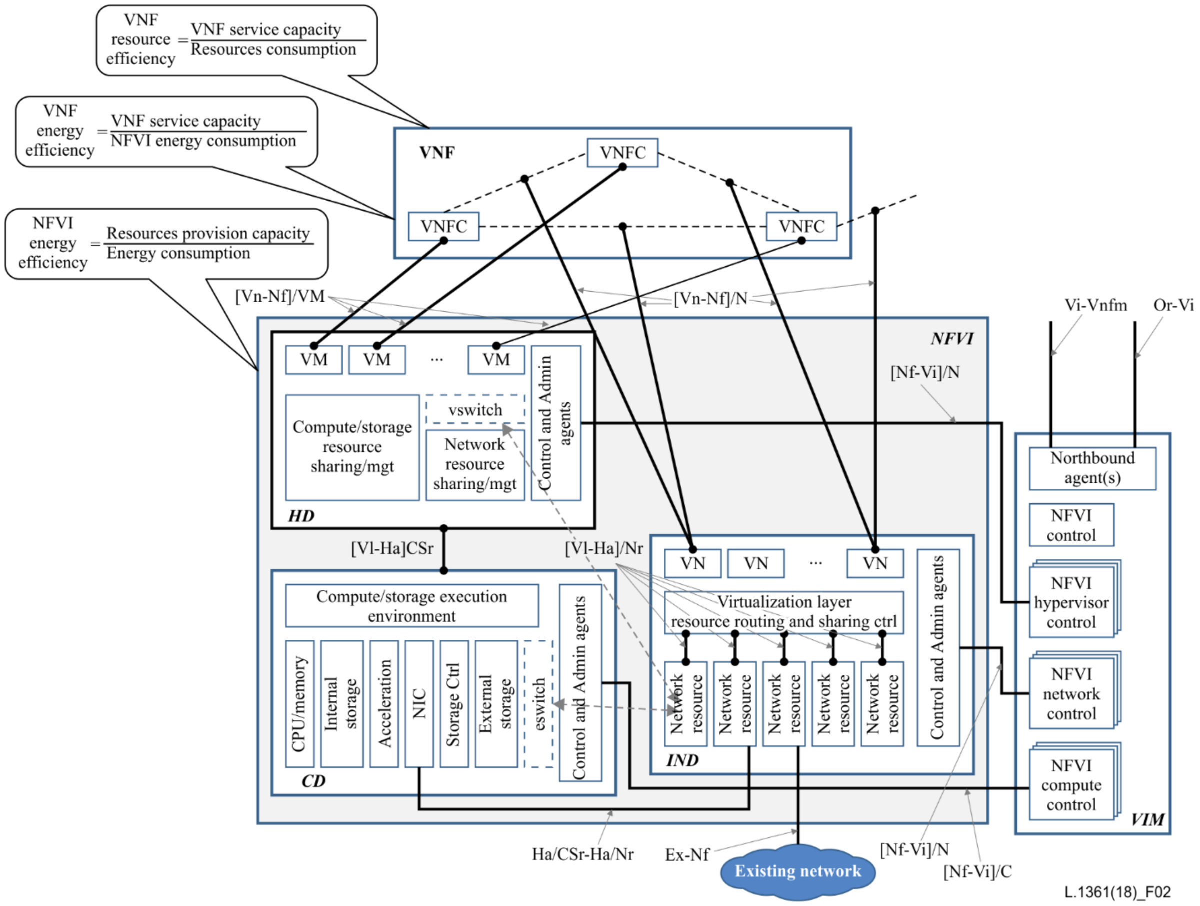

Figure 2 – High level NFV architecture – Adapted from [b-ETSI GS NFV-INF 001]

There are already several energy efficiency measurement standards for NFVI components, for example [b-SPECpower_ssj 2008] and [b-ETSI EN 303 470] for servers, [b-ETSI ES 203 136] for Ethernet switches, [b-SPEC VIRT_SC 2013] for virtualization systems.

The following clauses describe the SUTs considered for energy efficiency measurement, i.e., virtualized network functions (VNFs), the NFV infrastructure (NFVI).

The definitions of test environments and test functions are described in [b-ETSI GS NFV-TST 001]. The test environment consists of reference implementations of those functional NFV components from the NFV architecture which do not represent the particular SUT and contain test functions and entities to enable controlling of the test execution and collecting of the test measurements. Test functions are entities that communicate with the SUT via standardized interfaces.

VNF under test

For an energy efficiency measurement of a VNF, the SUT is a VNF under test as shown in Figure 3.

The test environment consists of a reference implementation of NFVI and MANO functional components plus a test controller, test VNF/PNFs, a performance monitor and a power meter. A performance monitor as test function is required to measure the performance indicators from the NFVI.

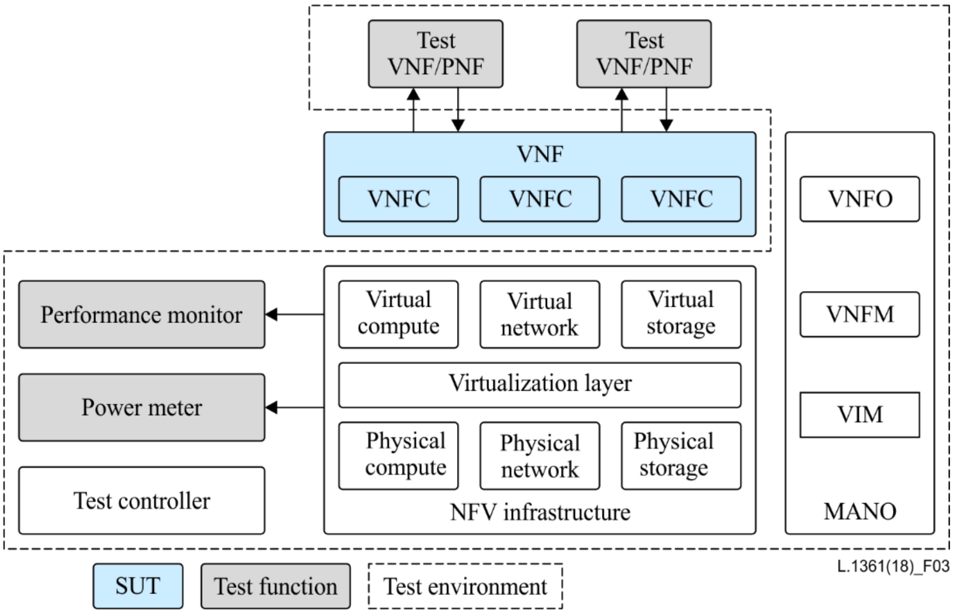

Figure 3 – Functional architecture for VNF under test

NFVI under test

For an energy efficiency measurement of a NFVI, the SUT is a NFVI under test as shown in Figure 4.

The SUT comprises physical hardware resources and virtual resources including computing, storage and network and virtualization layers.

The test environment consists of a reference implementation of the NFV MANO functional components plus a test controller, test PNFs/VNFs, reference VNFs, a performance monitor and a power meter.

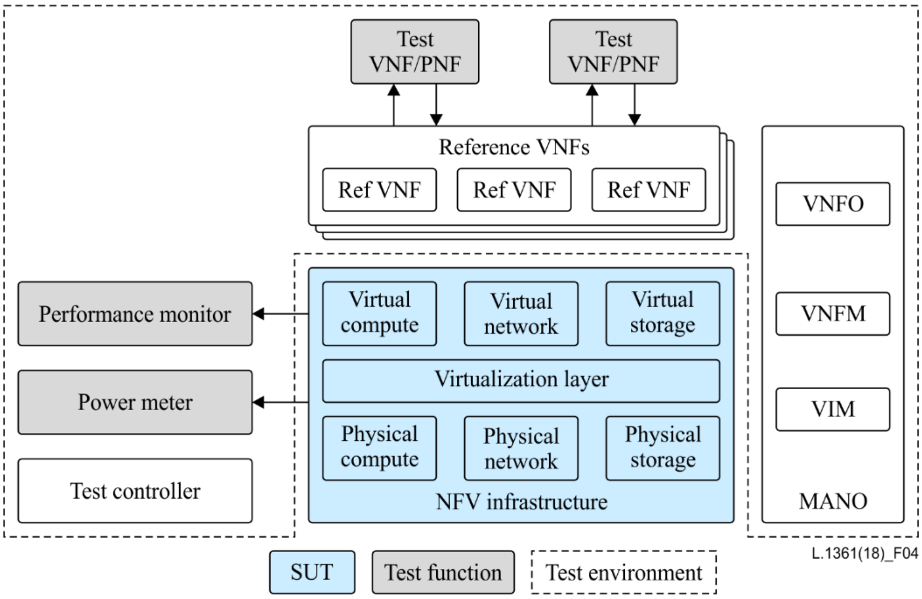

Figure 4 – Functional architecture for NFVI under test

6.2 Metrics for VNF

VNF is software application. Its energy consumption cannot be directly and hardware-independently measured with respect to the NFVI impact. Hardware has an idle power consumption regardless of the system activity and a dynamic power consumption caused by the software interactions with hardware components. Software can trigger hardware resources (e.g., CPU, memory, storage and network resources) to switch among different power states to influence the hardware resource utilization and energy consumption.

There are two methods to indirectly measure energy consumption of a VNF:

1) Measure the energy consumption of NFVI which only deploys a VNF under test.

2) Measure the resource consumption of a VNF under test which runs solely on a NFVI platform.

A VNF is scaled to provide different levels of service capacity by scaling one or more of its VNF components (VNFCs) depending on the work load. Most VNFs are designed with a fixed resource overhead for common management and control functions and elastic resources for service capacity. Increment of service capacity with VNF scaling is supported by resource increments. Different levels of VNF service capacity should be included in energy efficiency and resource efficiency metrics of VNFs. The number of levels could be decided based on typical capacity of specific types of VNFs. Generally at least three levels (minimum, maximum and medium) should be selected.

Figure 5 shows VNF scaling of service capacity and resource consumption.

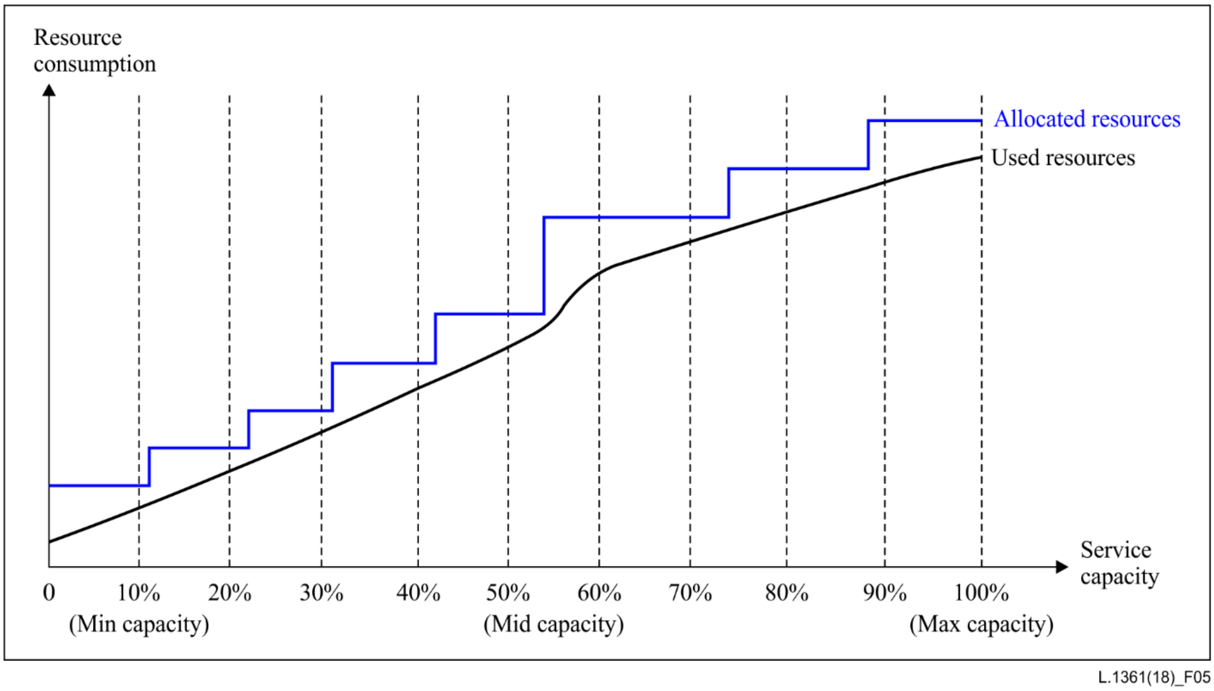

Figure 5 – VNF scaling of service capacity and resource consumption

6.2.1 VNF energy efficiency

The VNF's energy efficiency ratio (EER) metric is defined as:

$$VNF\_EER_i = \frac{\text{Useful output}}{\text{Power consumption}} = \frac{U_i}{P_i}$$

$$VNF\_EER = \sum_{i=1}^{N}(VNF\_EER_i \times w_i)$$

U_i is the useful output of VNF under service capacity level *i*. Depending on the different types of VNFs, it can be throughput (e.g., bit per second (bps), packet per second (pps)) for a data plane VNF, or capacity (e.g., number of subscribers or sessions) for a control plane VNF.

P_i is the power consumption of a NFVI platform introduced by a VNF deployed under service capacity level *i*.

VNF_EER_i is energy efficiency of a VNF under service capacity level *i*.

VNF_EER is weighted energy efficiency of all service capacity levels.

N is the total number of service capacity levels and w_i is the weight coefficient of level *i*.

6.2.2 VNF resource efficiency

The VNF's resource efficiency ratio (RER) metric can be defined as:

$$VNF\_RER_i = \frac{\text{Useful output}}{\text{Resource consumption}} = \frac{U_i}{\{R_{cpu}, R_{memory}, R_{storage}, R_{network}\}_i}$$

$$VNF\_RER = \sum_{i=1}^{N}(VNF\_RER_i \times w_i)$$

U_i is the useful output of VNF under service capacity level *i*. Depending on the different types of VNFs, it can be throughput (e.g., bps, pps) for a data plane VNF, or capacity (e.g., number of subscribers or sessions) for a control plane VNF.

VNF_RER_i is resource efficiency of VNF under service capacity level *i*.

VNF_RER is weighted resource efficiency of all service capacity levels.

N is the total number of service capacity levels and w_i is the weight coefficient of level *i*.

Resource consumption of virtual machines (VMs) allocated to a VNF SUT under service capacity level *i* is specified as follows:

R_{cpu} is CPU resource consumption, defined as used CPU capacity of the underlying VMs related to VNF.

R_{memory} is memory resource consumption, defined as total memory used of the underlying VMs related to VNF.

$R_{storage}$ is storage resource consumption, defined as total storage used of the underlying VMs related to VNF.

$R_{network}$ is network resource consumption, defined as the sum of average network throughput of bytes transmitted and received per second.

6.3 Metrics for NFVI energy efficiency

NFV infrastructure (NFVI) provides hardware resources and virtualized resources through a virtualization layer to support the deployment and execution of VNFs. The useful output of NFVI is resource provision capability. But the NFVI characteristics of resource provision depend on the VNF application. Energy efficiency of NFVI can be expressed as the service capacity of reference VNFs running on it with the amount of energy consumption.

The reference VNFs are either target VNFs to be deployed on a NFVI SUT, or general typical VNFs which can be categorized according to workload operations specified in [b-ETSI GS NFV-PER 001] as data plane, control plane, signal processing and storage workloads. The well-acknowledged open source telco-grade VNFs can be used as test functions in the latter case if they are developed by the industry community in the future. Some of the reference VNFs have been proposed as part of OPNFV Yardstick project [b-OPNFV], in which network service benchmarking (NSB) extends the yardstick framework to provide several sample VNFs (e.g., vPE, vCG-NAT, vFirewall).

The NFVI's energy efficiency ratio (EER) metric is defined as:

$$NFVI\_EER_{VNF_j} = \frac{\text{Useful output of VNF}_j}{\text{Power consumption}_j} = \sum_{i=1}^{N}\left(\frac{\text{U}_{i,j}}{\text{P}_{i,j}} \times w_i\right)$$

$$NFVI\_EER = \{NFVI\_EER_{VNF_j}\},\ j \in \{1,2,...\}$$

$U_{i,j}$ is the useful output of VNF_j under service capacity level *i*.

$P_{i,j}$ is power consumption of NFVI platform with VNF_j deployed under service capacity level *i*.

$NFVI\_EER_{VNF_j}$ is energy efficiency of NFVI platform with VNF_j deployed.

$NFVI\_EER$ is the aggregation of all energy efficiency of NFVI platform with different VNFs deployed.

7 Measurement methods

7.1 Measurement conditions

General information on measurement conditions and instrumentation requirements are contained in [ITU-T L.1315].

1) Configuration

All equipment parts of the SUT shall be generally available and orderable by customers. SUT should be tested under normal test conditions according to the information accompanying the equipment.

It is important in the SUT energy efficiency test to isolate the SUT as a black-box in order to ensure the test results not being influenced by other devices. However, it is very challenging to test a specific VNF without having the NFVI present or test a NFVI without a VNF present according to the nature of the NFV architecture. The recommended way to approximate SUT isolation in an NFV environment is to strictly control the configuration parameters of the NFV architecture elements that they do not comprise the SUT (i.e., the test environment) while varying configuration parameters for the SUT.

Test functions which usually are hardware-based tools can now be virtualized as well. A mechanism should be used in order to make test functions not compete for the resources with the SUT, otherwise the test results will not be reliable.

Used versions of SW, firmware, virtualization SW, HW, data plane acceleration mechanisms, power saving features and other test configurations shall represent the normal intended usage and be listed in the measurement report.

2) Environment conditions

The power measurements shall be performed in a laboratory environment under the conditions listed in Table 1.

Table 1 – Environment conditions

Condition	Minimum	Maximum
Barometric pressure	86 kPa (860 mbar)	106 kPa (1 050 mbar)
Relative Humidity	25%	75%
Temperature	+25°C	
Temperature accuracy	±2°C	

3) Power supply

The power supply shall be in accordance with conditions listed in Table 2.

Table 2 – Power supply

Type	Standard	Nominal value	Operating value for testing
DC 48 V	[ETSI EN 300 132-2]	−48 V	−54,5 V ± 1,5 V
Up to 400 V DC	[ITU-T L.1200]	260 – 400 V	380 V
AC	[ITU-T L.1315]	Single phase, 120 V	±5%, 60 Hz ± 1%
		Single phase, 230 V	±5%, 50 or 60 Hz ± 1%
		Three phase, 208 V	±5%, 50 or 60 Hz ± 1%

4) Measurement instruments

All measurement instruments used should be calibrated by a counterpart national metrology institute and within the calibration due date:

– 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 [ITU-T L.1315] and [b-IEC 62018].

7.2 Measurement procedure

The general measurement procedure consists of several steps as follows and as shown in Figure 6:

1) Define VNF service capacity levels to be tested based on specific type of VNF. Generally three levels of minimum, maximum and medium should be selected. The maximum capacity is decided according to the supplier's specification.

2) Set up NFVI configuration and VNF deployment for a capacity level to be tested. Number of virtual machines and physical machines, core and memory allocation, network configuration, deployment rules such as affinity and anti-affinity, acceleration techniques, etc. The test controller of the test environment configures and deploys VNF on the NFVI.

4) Workload generation based on pre-defined traffic profile of specific type of VNF. Workload could be provided by test VNFs/PNFs or an external traffic generator. The test controller triggers the execution of tests and controls the workloads dynamically.

5) Check pass/fail of VNF performance test. The QoS requirements of the VNF application need to be analysed to specify service level agreement (SLA) values used for comparison against measured values, such as latency, packet loss rate and loss probability, etc. The set of configuration parameters could be changed to achieve the SLA targets.

6) Power consumption, resource consumption and useful output measurement. Measurement results shall be captured earliest when the equipment including the selected load level is in stable operating conditions.

7) Test result collection and metrics calculation. To iterate test for all load levels defined in first step. During and after the test execution, the test controller collects the metrics measurement results from the test functions. The energy efficiency or resource efficiency metrics can be aggregated and calculated according to metrics definition in clause 6.

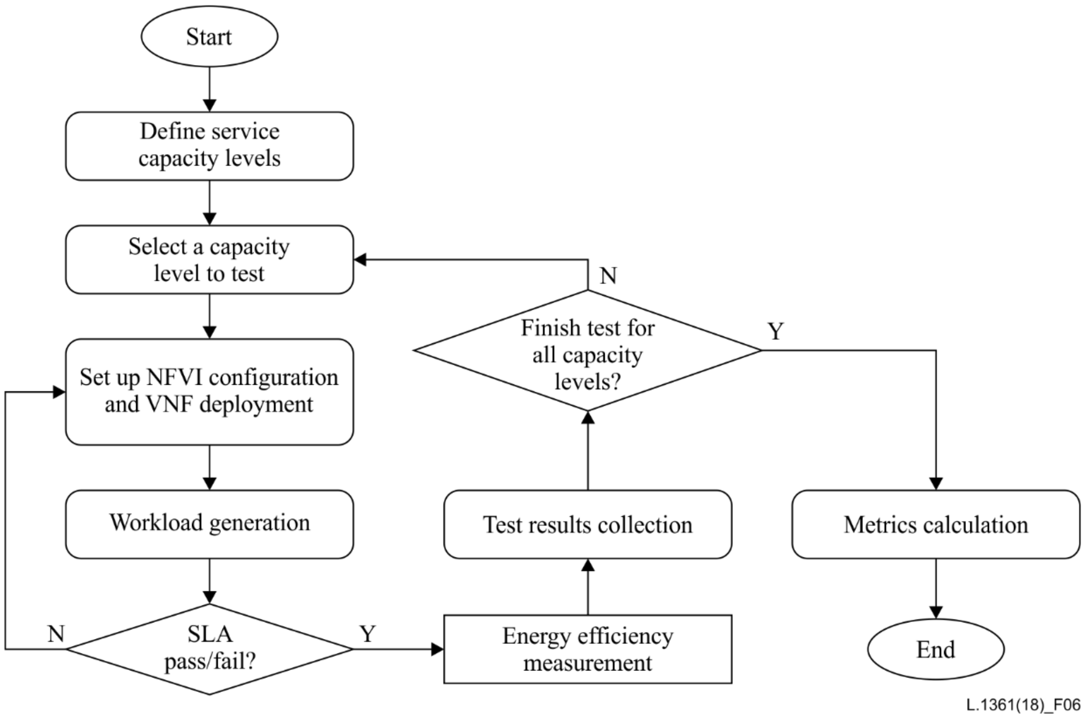

Figure 6 – General measurement procedure

7.3 Measurement method for power consumption of VNF

The power consumption of a VNF SUT is defined as increased power consumption caused by the VNF software interactions with NFV infrastructure. So the idle power consumption of NFVI without VNF deployment should be tested before the measurement procedure described in clause7.2. After finishing the test for each load level, the power consumption of the VNF SUT is calculated as power consumption of NFVI with idle power consumption subtracted.

$$P_i = P_{i\_load} - P_{i\_idle}$$

P_i is power consumption of NFVI platform introduced by VNF deployed under service capacity level *i*.

P_{i_load} is power consumption of NFVI platform with VNF deployed under service capacity level *i*.

P_{i_idle} is power consumption of NFVI platform without VNF deployed.

7.4 Measurement method for resource consumption of VNF

Virtual resource consumed by a VNF is the summary of resources of all VMs and virtual networks (VNs) allocated to the VNF. As the VNF SUT is the only VNF running on the NFVI, the virtual resource consumption of the VNF actually is the increment of physical resource consumption of NFVI after VNF deployment. So idle resource consumption of NFVI without VNF deployment should be tested before the measurement procedure described in clause 7.2. After finishing the test for each load level, the resource consumption of VNF SUT is calculated as resource consumption of NFVI with idle resource consumption subtracted.

$$R_i = R_{i\_load} - R_{i\_idle}$$

R_i is resource consumption of NFVI platform introduced by VNF deployed under service capacity level i. The resources include CPU, memory, storage and network.

$$R_i = \{R_{cpu}, R_{memory}, R_{storage}, R_{network}\}$$

R_{i_load} is resource consumption of NFVI platform with VNF deployed under service capacity level i.

R_{i_idle} is resource consumption of NFVI platform without VNF deployed.

Resource consumption can be measured through a performance monitor, which could be external monitor tools or monitor functions provided by NFV infrastructure.

R_{cpu} is calculated as average CPU utilization, see clause 6.6 of [ETSI GS NFV-TST 008], multiplied by clock speed in megahertz (MHz) of CPU and number of cores.

R_{memory} is total memory used by VNF, which is derived from other memory metrics, see clause 8.6 of [ETSI GS NFV-TST 008].

$R_{storage}$ is the amount of disk occupied by VNF on the host machine, see Annex A in [ETSI GS NFV-IFA 027]. As the methods of measurement for storage systems vary widely and depend on the implementation, storage metrics are not defined in [ETSI GS NFV-TST 008].

$R_{network}$ is the average network throughput of bytes transmitted and received per second by VNF external connection point, see clause 7.2 of [ETSI GS NFV-TST 008].

7.5 Measurement method for energy efficiency of NFVI

The reference VNFs are either target VNFs to be deployed on NFVI SUT or open source generic VNFs. For each reference VNF, the measurement process should follow the procedure defined in clauses 7.2 and 7.3.

The energy efficiency of NFVI is the aggregation of all energy efficiency metrics of NFVI with different reference VNFs deployed.

8 Measurement report

The measurement results shall be reported accurately, clearly, unambiguously and objectively and in accordance with any specific instructions in the required methods.

The measurement report shall include the following minimum information:

– All equipment software versions, hardware board revisions and device configurations used during the test. All commands applied to equipment for the purposes of static reconfiguration or run-time queries performed during the test should be disclosed.

– Traffic generator/measurement tool, actual voltage in power feeds and ambient (environmental) conditions at test site.

– The test set-up should be fully described, including topology, the choice of service capacity levels and test actions within a range of possible choices.

– Power and resource consumption measurement results, the calculated energy efficiency ratio (EER) or resource efficiency ratio (RER).

Appendix I

Example of VNF measurement

(This appendix does not form an integral part of this Recommendation.)

This appendix reports an example of results obtained in a measurement session that used this methodology.

I.1 General information

SUT: IMS telephony application server (TAS)

KPI: Resource efficiency of NFV, energy efficiency of NFV

Service capacity levels

Capacity	Min	Mid	Max
Subscribers	0.1 M	1 M	2 M
Weight coefficient	0.2	0.5	0.3

Traffic model

Types	Parameters	Unit	Value
Subscribers	Proportion of 2G/3G/4G subscribers	%	20%, 20%, 60%
	Proportion of VOLTE/ double standby /CSFB voice service subscribers	%	30%, 50%, 20%
	Proportion of VOBB subscribers(2G+3G)	%	1%
	Proportion of VOLTE subscribers roaming to 2G/3G	%	30%
Registration and mobility management	Number of initial registration per user during busy hours	times	0.75
	Number of re-registration per user during busy hours	times	2
	Number of logout per user during busy	times	0.5
	Number of xSRVCC switch per user during busy hours	times	0.3
	T-ADS number per user during busy hours	times	0.75
	STN-SR update number per user during busy hours	times	0.75
Call	voice call attempts per user during busy hours	times	1.5
	The average length of a voice call	second	60
	proportion of video calls (VoLTE-VoLTE)	%	24%
	Video call attempts per user during busy hours	times	1.5
	The average length of a video call	second	90
Intelligent services	Proportion of intelligent service subscribers	%	50%
	proportion of intelligent service play voice	%	10%

Types	Parameters	Unit	Value
Ring Back Tone(RBT)	Proportion of RBT user	%	90%
	RBT play time	second	20
Short Message Service(SMS)	Proportion of SMS user	%	100%
	Number of sending SMS per user during busy hours	times	3
	Number of receiving SMS per user during busy hours	times	1.5
proportion of supplementary service subscribers	Proportion of call forwarding	%	0.5%
	Proportion of call waiting	%	0.5%
	Proportion of caller ID	%	0.5%
	Proportion of call keeping	%	0.2%
Play ring-back tone	Proportion of play ringback tone	%	50%
	The average length of play ringback tone	second	15
	Traffic of play ringback tone	Erl	0.003125

Hardware configuration

	Virtual resource		Physical resource	
	VM_Type_1	**VM_Type_2**	**Server**	**Switch**
Specification / Capacity	vCPU:2 memory: 8G disk: 40G	vCPU:4 memory: 16G disk: 60G	Type: Rack server CPU:2*Xen E5-2650 v3 2.3GHz Disk: 4*SAS 300G Memory:192G	Type: L2 Switch 24*10G SFP
Min	3	4	1	1
Mid	3	13	2	1
Max	3	18	2	1

Software configuration

Software	Description
Hypervisor	OpenStack V100R006
MANO	V200R010
VNF	TAS V100R002

Test set-up

Figure I.1 shows the test set-up.

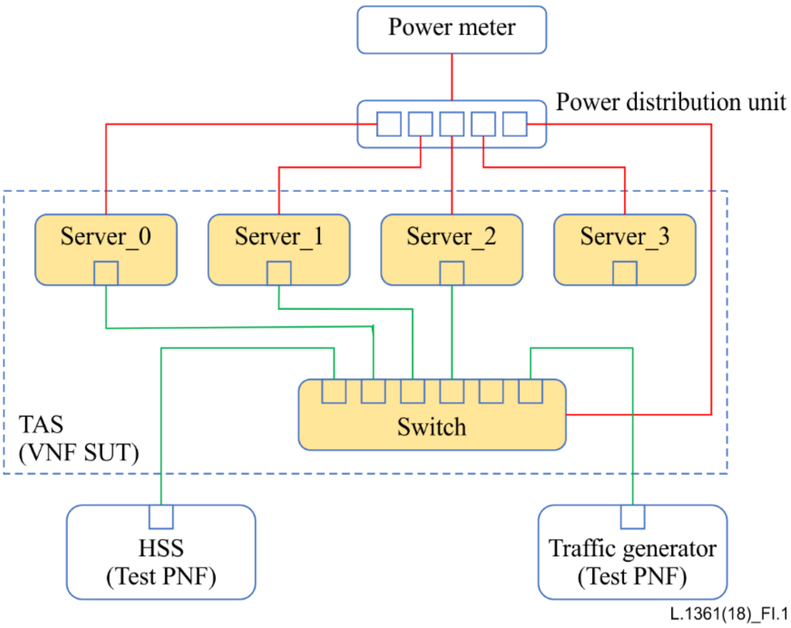

Figure I.1 – Test set-up

Test instruments

Test device	Number	Description
Traffic generator	1	IXIA 1xCatapult x800
Power meter	1	YOKOGAWA WT330
Home Subscriber Server (HSS)	1	

Test results

1) Energy efficiency (EE)

Load levels	Min	Mid	Max
U_i (subscribers)	0.1 M	1 M	2 M
P_{i_idle} (W)	200	400	400
P_{i_load} (W)	220	510	580
P_i (W)	20	110	180
VNF_EER_i (Subscribers/W)	5 000	9 091	11 111
w_i	0.2	0.5	0.3
VNF_EER (Subscribers/W)	8 878.8		

2) Resource efficiency (RE)

Load levels	Min	Mid	Max
U_i (subscribers)	0.1 M	1 M	2 M
R_{i_idle}(MHz)	138	322	322
R_{i_load}(MHz)	276	1 380	2 208
R_i (MHz)	138	1 058	1 886
VNF_RER_i (Subscribers/MHz)	725	945	1 060
w_i	0.2	0.5	0.3
VNF_RER (Subscribers/MHz)	935.5		

* Only consider CPU resource consumption for TAS, which is calculated based on CPU max frequency (2.3 GHz) and CPU utilization under different load levels.

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