RESERVE

D5.8 v1.0

Report on validation of ICT concepts using live 5G network, gateway and Pan-European infrastructure, V1

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Abstract:

The focus of the RESERVE project is to enable scenarios with up to 100% RES generation by using the new functionality which the 5th generation mobile communication network will provide.

This deliverable describes the power network protocols performance tests on the 5G ready mobile network under extreme conditions like maximal packet rate and peak traffic.

Keyword list:

Hardware in the loop simulation, power networks, voltage control, frequency control, 5G, LTE, NB-IoT, network slicing, latency, reliability, performance, Quality of Service.

Executive Summary

RESERVE has defined a wide range of scenarios for the use of 5G based ICT in the control of frequency and voltage in power networks as the percentage of Renewable Energy Sources (RES) generation increases towards 100%. In parallel, a power simulation and communications test infrastructure has been defined and described in D4.5.

In this deliverable, the results of the planning are described that have been undertaken to define:

- The tests can be performed with the infrastructure, and
- The set of scenarios that can be tested.

The power scenarios that can be measured include several scenarios for:

  - Two-level secondary frequency control,
  - Centralised, decentralised and distributed primary frequency control, and
  - Decentralised active and dynamic voltage control.

The test infrastructure is composed of 5G core network running at Ericsson in Aachen and a range of LTE and 5G prototype base stations set up in the laboratory at ACS in RWTH.

The tests which will be performed with the infrastructure will provide information on the likely latency, reliability and Quality of Service (QoS) which can be expected in a real network. The laboratory tests focus on the following test objects:

  - Power network communication protocols and
  - Mobile network features.

The plans for testing and measurement of 5G in the RESERVE power network scenarios will enable to quantify the effects of using new 5G communications networks on the frequency and control applications for power networks with up to 100% RES generation.

And last but not least, the planned test activities will prove validity of the possible adaptions and the new network codes for frequency and voltage control in networks with up to 100% RES generation.

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1. Introduction

1.1 The context of 5G measurements in RESERVE

RESERVE has defined a wide range of scenarios for the use of 5G based ICT in the control of frequency and voltage in power networks as the percentage of RES generation increases towards 100% and has described these scenarios in D1.3. In parallel, a power simulation and communications test infrastructure has been defined and described in D4.5.

In this deliverable, following points are detailed for future testing and validation of new techniques with 5G based ICT infrastructure:

- The tests that will be performed with the infrastructure, and
- The set of power network scenarios that are planned to be tested in RESERVE.

RESERVE laboratory infrastructure will enable to perform a wide range of realistic tests and measurements on the performance of 5G communication networks for a range of frequency and voltage control scenarios.

The power network scenarios described in this document are based on input from their on-going work on frequency and voltage control techniques in WP 2 and WP 3.

1.2 How to read this document

The relationship between the content of this document to existing and future deliverables in RESERVE is shown in Figure 1.

This deliverable is taking the following input from several deliverables:

- The list of ICT requirements from D1.3.
- Detailed description of the scenario models from WP2 and WP3. Note that detailed ICT requirements (e.g. quantified latency requirement) are still under discussion in these WPs.
- Laboratory infrastructure and test tools from D4.1
- General types of ICT experiments that can be run on the infrastructure from D4.5.
- ICT test setup from D4.5.
- The list of potential ICT technics and features from D4.5 that can be used in the network performance verification.

This deliverable is contributing in achieving the following objectives with several deliverables:

- Voltage control concept prove in the Irish field trial, and validation of initial network codes and anciliary service definitions with the deliverables D5.1 and D5.2,
- Frequency control concept prove in the laboratory, and validation of initial network codes and anciliary service definitions with the deliverables D5.4 and D5.5, and
- 100% renewable Irish scenario with the deliverable D5.6 and D5.7.

The results of this deliverable will be used to achieve the following goals of several deliverables:

- Definitions of anciliary services and network codes in the deliverable D6.3 and D6.4,
- CSR impact of business models and energy systems for the transition towards 100% RES in the deliverable D6.5 and D6.6,
- Promoting RESERVE network codes and anciliary services to standards organisations and stakeholders in the deliverable D7.2, and
- Promoting on workshops and other events (innovation and dissemination events, conferences, exhibitions) in the deliverable D7.3.

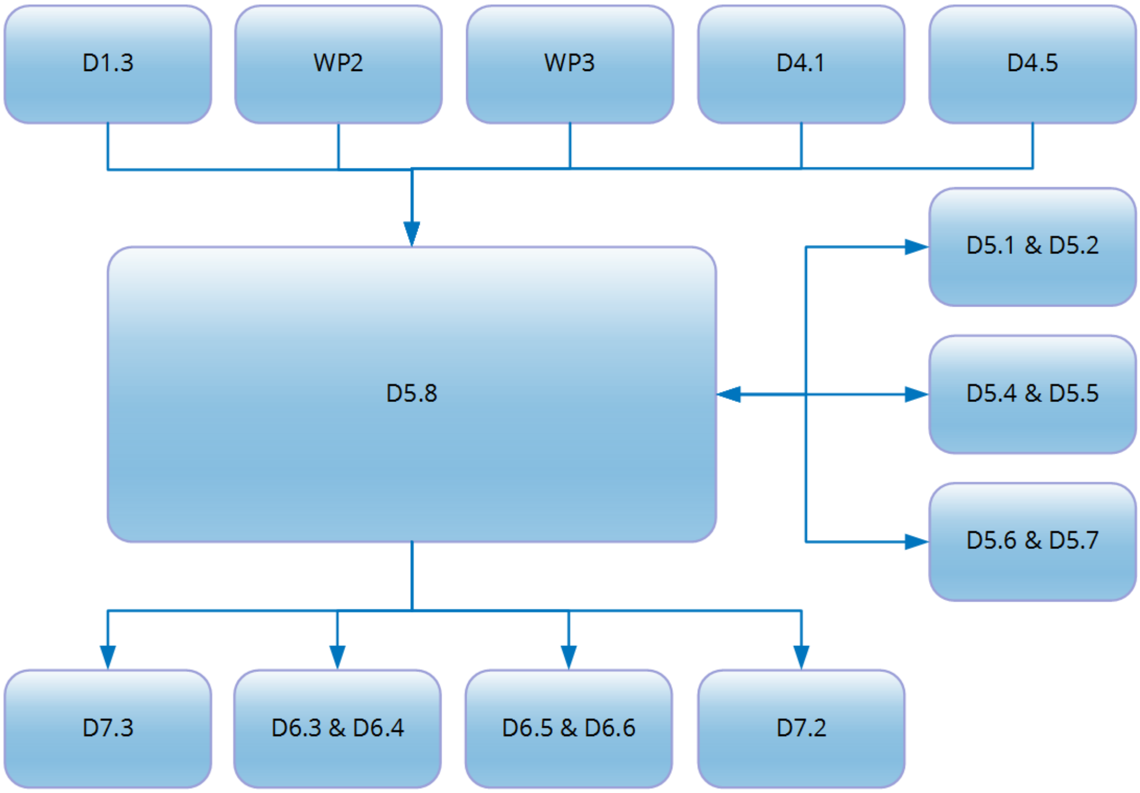

Figure 1 Relations between D5.8 and other deliverables

Chapter 2 describes the subset of RESERVE power network scenarios that are selected for the test in RESERVE project. Communication characteristics of the scenarios are shown. Furthermore, relationship between mobile network type and the power network scenarios is provided. Note that communication aspects of the power network scenarios considered in this chapter are not subject of the test plans described in this deliverable.

Chapter 3 describes the reference RESERVE infrastructure that will be utilised in RESERVE tests. Furthermore, it describes the communication features, and communication parameters that are relevant for the ICT tests described in this deliverable. Finally, it indicates the lab environment limitations comparing to the full scale deployed solution.

Chapter 4 describes the test objects and specifies test cases that will be executed in following months.

Chapter 5 provides a conclusion to this planning study.

2. RESERVE Scenarios for validation in test infrastructure

2.1 Mapping between power network scenarios and validation scenarios

Number of power network scenarios listed in Table 1 are considered in D1.3. They have been used as an input for defining several scenarios that will be validated in the test lab and the field trial. The mapping of the scenarios has been done keeping in mind to validate basic categories of the input power network scenarios. The following mapping principles have been taken into consideration:

- Communication requirements for both frequency scenario variants, Sf_A and Sf_B, are identical. The difference between these two variants is in the number of power generation points.
- 5G communications are utilised on relatively short distances (few kilometers), meaning that 5G communications are applicable rather to DSO networks.
- Mobile communications are cheaper solution compared to fibre on the communication path to small power generations (households). Additonally mobile communication does not have high frequency harmonic pollution issues which are there in fibre.
- 5G communications cannot be used in decentralised scenario architectures because the communication is happening on the local level where classical short distance communications are utilised.
- In RESERVE, secondary control concept is expanded to DSO segment where number of small gneration points are introduced that needs communications. Accordingly, secondary control DSO scenarios are of relevance for the communication tests.
- The solutions based on decentralised control architecture are not always the best choice which is proved in RESERVE tests. The reason is mainly inreliable frequency control on local level when non-synchronous machines are utilised. Therefore, distributed and centralised architectures are of an interest to a communication testing.

Original	Power	Scenarios	Validation Scenarios
Frequency Control	Inertial Control	TSO, Decentralized Control, Sf_A	-
		TSO, Decentralized Control, Sf_B	-
		TSO, Distributed Control, Sf_A	-
		TSO, Distributed Control, Sf_B	-
		DSO, Decentralised Control, Sf_A	-
		DSO, Decentralised Control, Sf_B	-
		DSO, Distributed Control, Sf_A	-
		DSO, Distributed Control, Sf_B	-
	Primary Control	TSO, Decentralized Control, Sf_A	-
		TSO, Decentralized Control, Sf_B	-
		TSO, Distributed Control, Sf_A	-
		TSO, Distributed Control, Sf_B, AC	-
		TSO, Distributed Control, Sf_B, HVDC	-
		DSO, Decentralised Control, Sf_A	FC 2
		DSO, Decentralised Control, Sf_B	FC 2
		DSO, Distributed Control, Sf_A	FC 3
		DSO, Distributed Control, Sf_B	FC 3
	Secondary Control	TSO, Centralised Control, Sf_A	-
		TSO, Centralised Control, Sf_B	-
		DSO, Centralised Control, Sf_A	FC 1
		DSO, Centralised Control, Sf_B	FC 1
Voltage Control		DSO, Dynamic voltage stability monitoring (Sv_A)	VC 1
		DSO, Decentralised active voltage control, Sv_B	VC 2

Table 1 Mapping of power network scenarios defined in D1.3 to validation scenarios

The following power scenarios will be validated in the test lab and the field trials:

- FC 1 – Two-level-secondary frequency control (UPB)
- FC 2 – Centralised primary frequency control provided by distribution system (UCD)
- FC 3 – Decentralised primary frequency control provided by distribution system (UCD)
- FC 4 – Distributed primary frequency control provided by distribution system (UCD)
- VC 1 – Decentralised dynamic voltage stability control (RWTH)
- VC 2 – Decentralised active voltage management control (UCD)
- For further details about validation scenarios please refer to D5.6.

2.2 Scenarios communication characteristics

The validation measurements put the focus to the communications between frequency/voltage control unit and the small power generations in the LV network. The communication takes place over the air interface.

The scenario data traffic characteristics are specified in Table 2 and Table 3. Traffic characteristics are related to the power network scenarios. Scenario FC 2 does not request over the air communications because the frequency measurements are processed locally by small power generations, i.e., they are not sent via the air interface. Accordingly, FC 2 is not in the validation scope.

Table 2 Scenarios and Communication Traffic Characteristics

Traffic Characteristic	**FC 1 Frequency Secondary Control**		**FC 2 Frequency Primary Decentralised Control**		**FC 3 Frequency Primary Decentralised Control**	**FC 4 Frequency Primary Distributed Control**	
Communication end-points	SPG to SSC	SSC to SPG	SPG to LDCC	LDCC to SPG	N/A	SPG to LDCC	LDCC to SPG
Protocol	SV/MQTT	AMQP/ MQTT	SV/MQTT	AMQP/ MQTT	N/A	SV/MQTT	AMQP/ MQTT
Inter arrival time	2 s	4 s	10-20 ms [1]	10-20 ms [1]	N/A	10-20 ms [1]	10-20 ms [1]
Message size [3]	1 KByte (f, power reserve band)	1 KByte (f)	1 KByte (P)	1 KByte (P)	N/A	1 KByte (P)	1 KByte (P)
Distance between end points in MV	10 – 50 km	10 – 50 km	1 – 5 km	1 – 5 km	N/A	1 – 5 km	1 – 5 km
Distance between end points in LV	2 – 3 km	2 – 3 km	< 1 km (e-car and photovoltaic panels on house)	< 1 km	N/A	< 1 km (e-car and photovoltaic panels on house)	< 1 km
No. of UEs in MV network	< 10 (photovoltaic panels, wind generations, storage)	< 10	< 10	< 10	N/A	< 10	< 10
No. of UEs in LV network	< 50 (small generator, photovoltaic panels on roof)	< 50	< 100 (< 1000)[2]	< 100 (< 1000)[2]	N/A	< 100 (< 1000)[2]	< 100 (< 1000)[2]
Reliability improvement	Not identified	Not identified	Message resending	Message resending	N/A	Message resending	Message resending

Note 1: Good – acceptable quality of the frequency control
Note 2: LDCC can be connected maximally to 1000 SPG in case that the antenna is covering the area controlled by 10 LDCCs.
Note 3: Message size will vary depending on the used protocol. Headers and meta data are considered.

f Frequency
FC Frequency Control
LDCC Local Data Controller and Concentrator
P Power
VC Voltage Control

Traffic Characteristic	VC 1 Dynamic Voltage Stability		VC 2 Active Voltage Management	
Communication end-points	SPG to VCU	VCU to SPG	SPG to VCU 4)	VCU to SPG
Protocol	SV/MQTT	AMQP/ MQTT	SV/MQTT	AMQP/ MQTT
Inter arrival time	N/A 3)	N/A 3)	20 ms	20 ms
Message size 3)	1: 10 Bytes 3: 76 Bytes	2: 144 Bytes	1 KByte (V, Q)	1 KByte (V, Q)
Distance between end points in LV	1 – 5 km	1 – 5 km	1 – 5 km	1 – 5 km
No. of UEs	<1000s	<1000s	<1000s	< 1000s
Reliability improvement	Not identified	Not identified	Message resending	Message resending

Note 4: Every hour or shorter the same message sequence is repeated.

V Voltage
Q Reactive power
VCU Voltage Control Unit

Table 3 Relationship between traffic characteristic and power network scenarios

End-to-end communications points

Communication in the test lab will be carried between real-time power network simulator and the mobile network. The communication end-point in the simulator is the simulated node Small Power Generation (SPG). SPG is the node that will be simulated in the ESB MV or LV power network simulation depending on the scenario. In practice, SPG in the LV network can be electric vehicle, photovoltaic panels on house, etc.

The following end-points are in the mobile network:

- 2nd level Secondary frequency Control (SSC)
- Local Data Controller and Concentrator (LDCC) used in frequency control
- Advanced power Voltage Control Unit (VCU)

LDCC is a cabinet next to MV/LV voltage transformer. Less than 100 SPGs generation can be connected to LDCC. One radio base station can cover an area controlled by several LDCCs, because the distance between two LDCCs can be up to 1 km. Therefore, one radio base station can be connected to maximally 1000 SPGs.

Protocols

In all power network scenarios, the following communication protocols are utilised and evaluated:

- In the uplink for collection of measurements:
  - Sampled Values (SV, IEC61850-9-2) [7], and
  - Message Queue Telemetry Transport (MQTT)
- In the downlink for control of inverters and devices:
  - Advanced Message Queuing Protocol (AMQP)
  - Message Queue Telemetry Transport (MQTT)

Inter arrival time

In the power network scenarios FC 1/2/4 and VC 2, the data are sent repeatedly in the intervals specified in Table 3. E.g., in scenario FC 1, the measurements are sent via the uplink every 2 s, and the instructions via the downlink every 4 s.

In scenarios FC 2 and FC 4, frequency control with high quality is achieved by refresh intervals of 10 ms, whereas acceptable quality is achieved by the 20 ms interval.

2.3 Relationship between mobile network type and power network scenarios

Different mobile network types are suitable for the validation scenarios. The relationship between mobile network type and validation scenarios is shown in Table 4. The following mobile network types are considered:

- 5G network
- 4G (LTE) network
- Narrow-Band IoT network (NB-IOT)
- enterprise LTE network (eLTE)

The 2nd level secondary frequency control scenario (FC 1) does not require ultra-low latency and high traffic, and it is not sensitive to the packet loss. Therefore, any type of the mobile network can be utilised in scenario FC 1.

In the primary centralised and distributed frequency control scenario (FC 2 and 4), only 5G network can be utilised because ultra-small latency is required.

Although all mobile network types can be utilised in voltage control scenarios (VC 1 and 2), better voltage control will be achieved with 5G network, because lower transmission latency will cause shorter control mechanism cycles that will improve the voltage control quality.

Mobile Network Type	FC 1 Secondary	FC 2 Primary Centralised	FC 3 Primary Decentralised	FC 4 Primary Distributed	VC 1 Dynamic	VC 2 Active
5G	X	X	N/A	X	X	X
4G (LTE)	X		N/A		X	X
NB-IOT	X		N/A		X	X
eLTE	X		N/A		X	X

Table 4 Relationship between mobile network type and power network scenarios

3. RESERVE 5G based ICT Test infrastructure

3.1 RESERVE test block chart

Figure 2 shows the block chart of the RESERVE test infrastructure with all relevant HW and SW components. The test infrastructure comprises of power and communication components, both physical and software.

Two kinds of tests will be done in RESERVE:

- The lab test with the real-time power network simulator, and
- The field trial.

In both cases a physical mobile network will be utilised. The mobile network will be connected to the real-time power network simulator, and the field devices located in ESB network in Ireland.

In the test lab, power grid simulator will be equipped with the ESB Medium Voltage (MV) simulation data for the frequency scenario simulations, and ESB Low Voltage (LV) data for the voltage scenario simulations. The 5G ready mobile network will be connected to the power network simulator. New concepts like Network Slicing [13] are integrated in the mobile network. Advanced power frequency and voltage control algorithms will be deployed in the distributed cloud in the mobile network. This infrastructure will be utilised for Hardware-in-the-Loop (HIL) tests in the test lab.

In the field trial test, the mobile network will be connected to the field trial devices (solar panel, grid2vehicle charger, etc.) in ESB distribution network connected via SERVO platform.

This deliverable describes only **tests** that will be conducted on 4G or 5G ready mobile network.

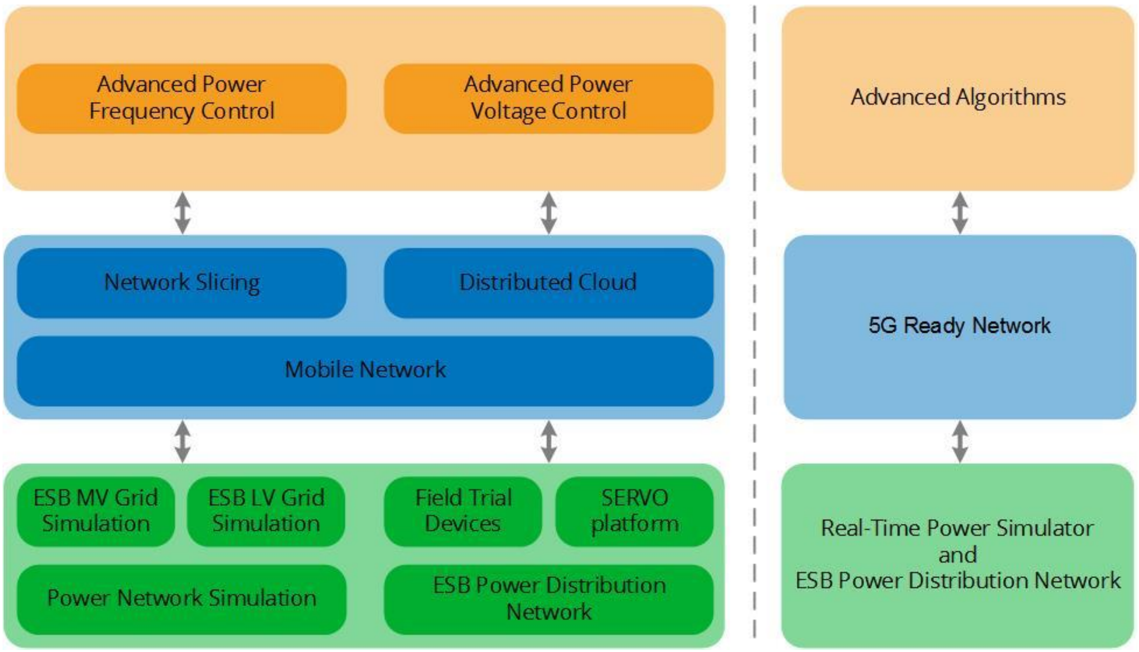

Figure 2 RESERVE test block chart

3.2 Test bed and SW/HW components

3.2.1 Test network plan

The test infrastructure comprises the following equipment:

- VILLASnode gateway software which interfaces simulators with ICT protocols,
- User Equipment (UE) to connect to the 4G/5G network, and
- 5G ready/4G mobile network consisting of the flight-rack and the radio base station.

In the context of the ICT 5G performance test, VILLASnode (see D4.1) will be utilised for traffic generation and analysis. Therefore, VILLASnode will not play the co-simulation gateway node role which is its primary role in RESERVE project. Instead, VILLASnode will send packets in variable size and rate, and will also capture and collect statistics about the communication characteristics by logging of time stamps and packet sequence numbers. For these tests, VILLASnode instances will be deployed on the lab PC that will be connected to the UE, and on the 5G/4G flight-rack.

3.2.2 5G ICT lab test methodology

The 5G ICT test will be done with the emulated traffic generated by VILLASnode. VILLASnode will be deployed on both sides of the radio link. VILLASnode will act either as sender or the receiver of the data stream. By using VILLASnode, the same software implementation of the tested communication protocols will be used for the validation of the ICT infrastructure as well as for the simulation test cases which will be later-on carried out to validate the novel WP2/3 control algorithms. This is crucial in order to guarantee comparable results.

Test configuration:

- 5G/4G network deployed on the flight rack
- 5G/4G User Equipment (UE)
- VILLASnode deployed on the virtual machine on the flight rack
- VILLASnode deployed on the lab PC connected to 4G/5G User Equipment (UE)

Test methods:

- VILLASnode on the sending side will act as a traffic generator and send measurements as well as control messages via the radio link.
- VILLASnode will generate the packets periodicaly with the size that correspond to the emulated protocol, and add time stamp to every packet.
- VILLASnode on the receiving side will capture received packages.
- Only one-way traffic stream will be analysed (e.g., no round trip time will be considered).
- The following emulated protocols will be used per specified direction:
  - In the uplink[1]:
    - Sampled Values (SV, IEC61850-9-2) [7], and
    - Message Queue Telemetry Transport (MQTT)
  - In the downlink[2]:
    - Advanced Message Queuing Protocol (AMQP)
    - Message Queue Telemetry Transport (MQTT)
- The protocols SV[3] and MMQT will be utilised for the data transmission towards control unit in distributed cloud. SV is utilised for the measurements collection in the real deployments currently, whereas MMQT is still not deployed. As MQTT is machine-to-

[1] An "uplink" is a unidirectional radio link for the transmission of signals from a UE to a base station, from a Mobile Station to a mobile base station or from a mobile base station to a base station.

[2] An “downlink” is a unidirectional radio link for the transmission of signals from a UTRAN access point to a UE. Also, in general the direction from Network to UE.

[3] SV is not routable protocol. To enable routing of SV messages to the control unit in the Distributed Cloud, two SV variants will be tested in the lab: (i) SV over GRE tunnel, and (ii) Routable SV. However, performance behaviour of both SV variants is identical as both are encapsulating SV in a similar way. Only packet size is slightly different.

machine/ Internet of Things" connectivity protocol, it might be utilised in the future power network. Therefore, performance comparison of SV and MQTT will be done in the test.

- SV and MQTT will be used for the measurement data transmission from the SPG to the frequency or voltage control unit.
- On the air downlink, AMQP will be utilised for instructions (commands) transmission from the control unit to the SPG for comparison against MQTT.

3.2.3 Mobile network features utilised in tests

Mobile network features that are utilised in the test are described in this chapter. Network slicing and Quality of Service [17] features will improve reliability of the dedicated power frequency and voltage control traffic in peak traffic situations.

3.2.3.1 Quality of service provisioning

QoS provisioning allows the mobile network to distinguish between different types of traffic and enhances the reliability of the network per individual traffic type.

Evolved Package System (EPS) is a connection-oriented logical network and enables the establishment of a virtual connection (EPS bearer) between UE and Packet Gateway (PGW). Every time an UE connects with mobile network, it gets a default EPS bearer and receives QoS treatment defined with QoS attributes for its end-to-end connectivity. The QoS requirements for each bearer are indicated by the QoS Class Identifier (QCI). The QCI classes are defined by 3GPP specifications and are illustrated in Table 5.

The discrete QCI value indicate the characteristics of the bearer such as priority order, packet delay budget and packet loss rate.

Table 5 QCI classes

QCI	Resource Type	Priority	Packet delay budget (ms)	Packet loss rate	Example Services
1	GBR	2	100	10^{-2}	Conversational Voice
2		4	150	10^{-3}	Conversational Video (Live Streaming)
3		3	50	10^{-3}	Real Time Gaming
4		5	300	10^{-6}	Non-Conversational Video (Buffered Streaming)
5	Non-GBR	1	100	10^{-6}	IMS Signalling
6		6	300	10^{-6}	Video (Buffered Streaming), TCP-based (e.g., www, e-mail, ftp, etc.)
7		7	100	10^{-3}	Voice, Video (Live Streaming)
8		8	300	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, ftp, etc.)
9		9			
GBR – Guaranteed Bit Rate					

3.2.3.2 Network slicing

Network slicing enables the operator to create networks customised to provide optimized solutions for different market scenarios which demands diverse requirements, e.g. in the areas of functionality, performance, and isolation.

A network slice fulfils at least a couple of purposes for a UE:

- It offers UE particular system behaviours tailored to specific application needs, from the standpoint of specific control plane (e.g. Critical communications) or user plane behaviours (e.g. the UE may need a slice supporting header compression)
- It offers a UE access to resources allocated for a specific Service or Application domain, or a Tenant (e.g. minimum level of guaranteed resources or aggregate number of subscribers allowed to access the service at any point in time)

  In summary, Tenant represents an organization, agency, application (or application class) or business entity which is entitled to access the service for the use of guaranteed network resources through a predefined Service Level Agreements and Policies with the network operator.

Figure 3 depicts a network that is supporting n tenants and up to m network behaviours (slice types) in both the Radio Access Network and the core.

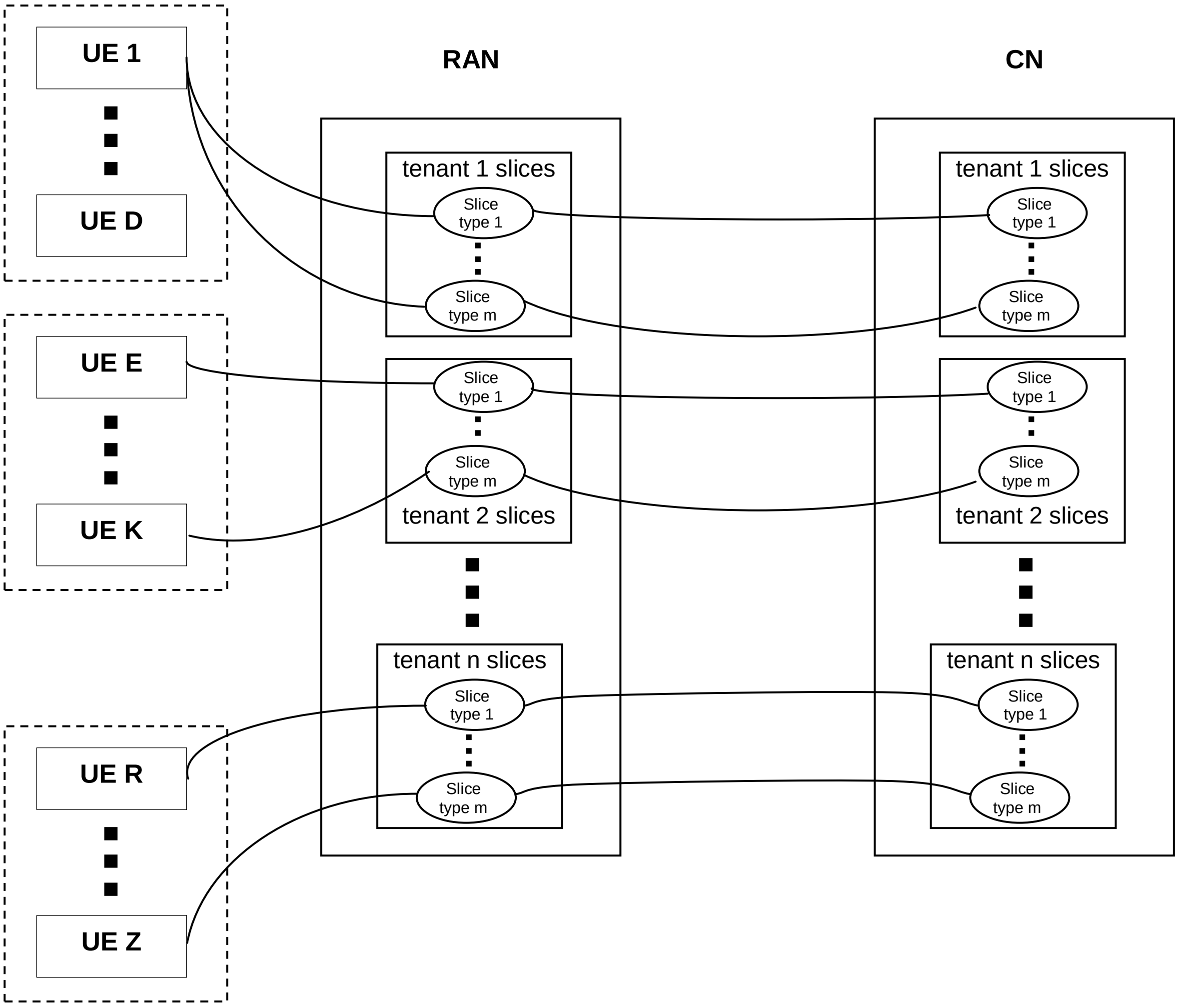

Figure 3 Network with n Tenants and m possible Slice Types (with UEs which can only access a single tenant slices)

Network slicing will be utilised in the test lab to validate if it improves the power network stability in the test scenarios.

3.2.4 Communication parameters measured in tests

3.2.4.1 User plane latency

User plane latency [14] is the time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by Discontinuous Reception (DRX) [10].

For URLLC, the target for user plane latency should be 0.5ms for uplink, and 0.5ms for downlink. The reference network deployment, as described in chapter 3.3, applies here.

3.2.4.2 Reliability

Reliability, as defined in 5G 3GPP standard [14], can be evaluated by the success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 Service Data Unit (SDU) ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a certain channel quality (e.g., coverage-edge).

A general Ultra-Reliable and Low Latency Communications (URLLC) reliability requirement for one transmission of a packet is $1\text{-}10^{-5}$ for 32 bytes with a user plane latency of 1ms. The reference network deployment, as described in chapter 3.3, applies here.

3.3 5G reference deployment architecture

This chapter describes the following 5G network reference deployment scenarios for Ultra-Reliable and Low Latency Communications (URLLC) as defined per 3GPP standard [14] that are of particular interest for the power network scenarios that will be validated:

- Dense urban
- Rural

Relevant attributes for both scenarios are listed in

Attributes	Values or assumptions	
	Dense urban	Rural
Carrier Frequency	Around 4 GHz + Around 30 GHz (two layers)	Around 700 MHz or around 4 GHz (for ISD 1) Around 700 MHz and around 2 GHz combined (for ISD 2)
Inter-Site Distance (ISD)	200 m	ISD 1: 1732 m ISD 2: 5000 m

3.4 Relationship between laboratory and a full-scale deployment 5G based ICT infrastructure

It is understandable that validation in a lab environment is bringing some limitations comparing to the full scale deployed solution. The following limitations are identified:

- No handover, device stationary and in fixed relationship of distance to the base station.
- In a full-scale deployment solution scenario, devices would have a range of distances to the nearest base station which will affect the signal strength and performance characteristics of the individual radio links to these devices.
- The hardware and software characteristics of the equipment and deployed software used in the lab can differ from the hardware and software used in a full scale live infrastructure. E.g., processor, memory and discs performance, software versions, etc.
- There will be less interferences on the radio interface in the test lab, and the devices will have optical visibility to the antenna. In a real deployment, there will be obstacles in the environment, many reflected signals, each with a different time delay and phase, arrives at the receiver, etc.
- In a test environment, limited number of traffic types can be utilised comparing to the full range of traffic types in a real-world applications.

- A packet loss in a real environment is certainly higher than in a test lab.
- Instead of Manufacturing Message Specification (MMS) protocol [12] utilised in the power networks, Advanced Message Queuing Protocol (AMQP) [9] will be emulated in the lab test.

Relationship between power network simulations and a real-world application is described in deliverable D5.6 [3].

4. Test objects

The following two test objects are defined in the scope of the 5G based ICT lab test:

- Power network communicaiton protocols, and
- 5G ICT based mobile network features

The performance of the **power network communication protocols** will be evaluated in a wide range of traffic profiles (different packet size and rate). Therefore, performance of the different power network communication protocols will be able to compare in different power network scenarios. Additionally, the power network communication protocol behaviour will become well defined segment during the power network scenario tests preparation.

The power network communication protocol parameters, as latency and reliability, are of upmost importance for power network scenarios that will be validated in RESERVE tests. Accordingly, latency and reliability of the network power communication protocols will be validated. Maximum update rate and recoverability from connection loss are further parameters that will be validated.

The result of every test case, that will be executed in the lab, will be one of the above specified power network protocol characteristics. Every test case will have one adjustable input parameter.

The second test object is **5G ICT based mobile network features**. The performance of the mobile network will be evaluated in a peak traffic situation when the new mobile network features are applied. Again, packet latency and transmission reliability will be measured parameters.

The result of every test case related to this test object will packet latency and transmission reliability. Every test case will have one adjustable input parameter.

Table 6 summarizes test objects and test cases identified during this document preparation that are the most relevant for the power network scenarios.

Priority	Test Object	Adjustable Input Test Variable	Test Result	Test Objective
Recommended	Power network protocols	Packet rate	User plane latency	Test how different sending rates impact the end-to-end delay depending on the protocols (for each protocol).
Recommended	Power network protocols	Packet rate	Packet loss / reliability	Test how the sending rate affects the packet loss probability and correlation (sporadically vs. bursts) of it.
Recommended	Power network protocols	Packet size	Maximum update rate	Determine the maximum update rate for which the given protocol can be used.
Recommended	Power network protocols	Outage duration	Recoverability from connection loss	Test how different protocols can **recover** from outages with regard to expected delay of delivery and packet loss.
Recommended	Mobile network features	Peak traffic	User plane latency	Compare influence of a peak traffic depending on network features (network slicing, QoS)
Recommended	Mobile network features	Peak traffic	Packet loss / reliability	Compare influence of a peak traffic depending on network features (network slicing, QoS)

Table 6 5G based ICT lab test cases

4.1 Test object: Power network communication protocols

4.1.1 Test case: User plane latency

Test case definition:

Test Name	Power network communication protocols - user plane latency
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD) • Zain Mehdi (EDD)
Test Objective	Test how different sending rates impact the end-to-end delay depending on the protocols (for each protocol).
Test Description	Measure user plane latency on the communication link between VILLASnodes deployed on the lab PC and the 5G flight-rack. Latency will be measured repeatedly for different packet rates, and for different protocols.
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 instances of VILLASnode gateway software • 4G/5G UE
Test Parameters	• Test duration: 1-10 min per fixed packet rate • Protocol: AMQP, MQTT, SV
Test Variables	• Packet rate (packets per second): 1, 10, 100, 1000…
Test Results	• User plane latency
Steps	(Steps 1-5: Uplink measurements) 1. Configure the test parameters (packet rate, test duration, packet size, etc…) in VILLASnode on UE side. 2. Ensure that clocks are synchronised on sending and receiving VILLASnodes. 3. Start the traffic from VILLASnode on UE side towards the receiving VILLASnode on edge cloud. 4. Logging the time stamps on VILLASnode on edge cloud 5. Create the latency graph of collected measurements using Matlab or Awk script 6. Repeat the steps 1-5 for downlink measurements
Pass Criteria	Defined user packet latency distribution curves for different packet rates.
Suspension Criteria	-

Test case preparation:

Date	
Authors	• Zain Mehdi (EDD) • Robert Farac (EDD)
Preparation	1. Connect 4G/5G UE with VILLASnode 2. Check the connectivity between UE and flight rack
Protocol	

4.1.2 Test case: Reliability

Test case definition:

Test Name	Power network communication protocols – reliability
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD) • Zain Mehdi (EDD)
Test Objective	Test how the sending rate affects the packet loss probability and correlation (sporadically vs. burst) of it.
Test Description	Measure packet loss on the communication link between VILLASnodes deployed on the lab PC and the 5G flight-rack. Packet loss will be measured repeatedly for different packet rates, and for different protocols. Packet loss will be measured in an off-peak traffic situation
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 instances of VILLASnode gateway software • 4G/5G UE
Test Parameters	• Test duration: 10 min per fixed packet rate • Protocol: AMQP, MQTT, SV
Test Variables	• Packet rate (packets per second): 1, 10, 100, 1000…
Test Results	• Packet loss
Steps	(Steps 1-5: Uplink measurements) 1. Configure the test parameters (packet rate, test duration, packet size, etc…) in VILLASnode on UE side. 2. Ensure that clocks are synchronised on sending and receiving VILLASnodes. 3. Start the traffic from VILLASnode on UE side towards the receiving VILLASnode on edge cloud.

	4. Determine percentage of packet loss by counting gaps in packet sequence numbers in relation to total number of sent packets. This statistic is calculated on-the-fly by the receiving VILLASnode instance or can be gathered by post-processing the received data with a Matlab or Awk script 5. Create the latency graph of collected measurements using Matlab or Awk script 6. Repeat the steps 1-5 for downlink measurements
Pass Criteria	Defined packet loss distribution curves for different packet rates.
Suspension Criteria	-

Test case preparation:

Date	-
Authors	• Zain Mehdi (EDD) • Robert Farac (EDD)
Preparation	1. Connect 4G/5G UE with VILLASnode 2. Check the connectivity between UE and flight rack
Protocol	

4.1.3 Test case: Maximum update rate

Test case definition:

Test Name	Power network communication protocols – maximum update rate
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD)
Test Objective	What is the maximum update / packet rate under which the communication medium shows normal packet loss and deterministic communication latencies?
Test Description	With increasing packet / updates rates it is expected to see increased packet loss and higher jitter in the communication latencies. This test should determine the maximum packet rate which the mobile network can handle without showing effects of congestion (packet loss, increased latency and higher jitter).
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 instances of VILLASnode gateway software • 4G/5G UE
Test Parameters	• Test duration: 10 min per fixed packet rate • Protocol: AMQP, MQTT, SV

Test Variables	• Update rate (packets per second): 1, 10, 50, 100, 1000, 2000, 5000
Test Results	• Communication latency histograms and packet loss percentages for varying update rates.
Steps	(Steps 1-5: Uplink measurements) 1. Configure the test parameters (packet rate, test duration, packet size, etc…) in VILLASnode on UE side. 2. Ensure that clocks are synchronised on sending and receiving VILLASnodes. 3. Start the traffic from VILLASnode on UE side towards the receiving VILLASnode on edge cloud. 4. Create the latency graph of collected measurements using Matlab or Awk script Repeat the steps 1-5 for downlink measurements
Pass Criteria	The system must handle at least 50 updates a second without increased communication latencies or packet loss from idle conditions.
Suspension Criteria	-

Test case preparation:

Date	-
Authors	• Steffen Vogel (RWTH) • Zain Mehdi (EDD)
Preparation	1. Connect 4G/5G UE with VILLASnode 2. Check the connectivity between UE and flight rack
Protocol	

4.1.4 Test case: Recoverability from connection loss

Test case definition:

Test Name	Power network communication protocols – recoverability
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD)
Test Objective	How do tested communication protocols handle outages of the communication medium and subsequent restoration of connectivity?
Test Description	Peculiarities of the tested communication protocols (AMQP, MQTT, SV) and underlying transport protocols (TCP, UDP) as well as the networking stack of the operating systems might have negative side-effects when connectivity is interrupted and later on restored.

	This test shall identify problems and undesired side effects caused by implementation details of protocols as well as quantify the impact of an outage towards latency and packet loss. Can the system fully recover without manual intervention? How much time passes until the system returns to nominal conditions?
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 instances VILLASnode software • 4G/5G UE
Test Parameters	• Test duration: 10 min per fixed packet rate • Protocol: AMQP, MQTT, SV
Test Variables	• Duration of outage (seconds): 1, 10, 100
Test Results	Measurements of timespans until return to nominal conditions after outages.
Steps	• Configure the test parameters (packet rate, test duration, packet size, etc…) in VILLASnode on UE side. • Ensure that clocks are synchronised on sending and receiving VILLASnodes. • Start the traffic from VILLASnode on UE side towards the receiving VILLASnode on edge cloud. • Interrupt mobile connectivity to base station by pausing the PPP daemon in the UE. • Wait for varying amounts of time (1, 10, 100 seconds) • Restore connectivity by resuming the PPP daemon in the UE. • Create plots of communication latency as well as packet loss over time of the whole test.
Pass Criteria	The system should return without manual interventions to nominal conditions within a timespan of less than 1 minute.
Suspension Criteria	-

Test case preparation:

Date	
Authors	• Zain Mehdi (EDD) • Steffen Vogel (RWTH)
Preparation	• Connect 4G/5G UE with VILLASnode • Check the connectivity between UE and flight rack
Protocol	

4.2 Test object: Mobile network features

4.2.1 Test case: User plane latency

Test case definition:

Test Name	Mobile network features – user plane latency
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD) • Zain Mehdi (EDD)
Test Objective	Compare influence of a peak traffic to a dedicated traffic depending on network features (network slicing, QoS)
Test Description	Measure user plane latency in an off-peak as in a peak traffic situation. Then measure user plane latency when applied network slicing (5G) or quality of service (4G).
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 VILLASnodes • 4G/5G UE • Network slicing (5G) or Quality of service feature (4G) • iPerf tool [1] for the traffic generation
Test Parameters	• Duration: 10min by increasing traffic intensity (i) when network feature applied and (ii) when does not. • Enable/Disable QoS Class Identifier (QCI) for particular traffic
Test Variables	• Traffic intensity
Test Results	• User plane latency
Steps	1. Measure user plane latency between VILLASnodes by increasing traffic intensity, and 2. Measure user plane latency between VILLASnodes by increasing traffic intensity when defined network slice (5G) or quality of service (4G).
Pass Criteria	User plane latency curves depending on traffic intensity (i) with and (ii) without defined network slicing (5G) or quality of service (4G)
Suspension Criteria	-

Test case preparation:

Date	
Authors	• Zain Mehdi (EDD) • Robert Farac (EDD)

Preparation	1. Connect 4G/5G UE with VILLASnode 2. Check the connectivity between UE and flight rack
Protocol	

4.2.2 Test case: Reliability

Test case definition:

Test Name	Mobile network features – reliability
Authors	• Steffen Vogel (RWTH) • Robert Farac (EDD) • Zain Mehdi (EDD)
Test Objective	Compare influence of a peak traffic to a dedicated traffic depending on network features (network slicing, QoS)
Test Description	Measure a packet loss in an off-peak as in a peak traffic situation. Then measure a packet loss when applied network slicing (5G) or quality of service (4G).
Test Location	RWTH Aachen lab
Test Environment	• Flight rack (5G, LTE or eLTE) with antenna • 2 VILLASnodes • 4G/5G UE • Network slicing (5G) or Quality of service feature (4G) • iPerf tool for the traffic generation
Test Parameters	• Duration: 10min by increasing traffic intensity (i) when network feature applied and (ii) when does not. • Enable/Disable QoS Class Identifier (QCI) for particular traffic
Test Variables	• Traffic intensity
Test Results	• Packet loss
Steps	1. Measure packet loss between VILLASnodes by increasing traffic intensity, and 2. Measure packet loss between VILLASnodes by increasing traffic intensity when defined network slice (5G) or quality of service (4G) for the measured traffic.
Pass Criteria	Packet loss curves depending on traffic intensity (i) with and (ii) without defined network slicing (5G) or quality of service (4G)
Suspension Criteria	-

Test case preparation:

Date	
Authors	• Zain Mehdi (EDD) • Robert Farac (EDD)
Preparation	1. Connect 4G/5G UE with VILLASnode 2. Check the connectivity between UE and flight rack
Protocol	

5. Conclusion

The plans for testing and measurement of 5G in RESERVE power network scenarios will enable us to investigate the performance of the 5G communication networks for the new frequency and voltage control scenario defined in the context of the RESERVE project.

This document provides detail plan including infrastructure setup and key performance indicators planned to validate new upcoming 5G features (Network slicing, Distributed cloud) for voltage and frequency control application.

6. References

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7. List of Abbreviations

3GPP	3rd Generation Partnership Project, mobile communications standardisation body
4G	4th Generation mobile communications system
5G	5th Generation mobile communications system
AMQP	Advanced Message Queuing Protocol
APN	Access Point Name
BRGW	Breakout Gateway
CN	Core Network
DCS	Data Centric Security
DRX	Discontinuous Restriction
DS	Distribution System
DSO	Distribution System Operator
eLTE	enterprise Long Term Evolution
eNB	E-UTRAN Node B, evolved Node B
EPS	Evolved Package System
ESB	Electricity Supply Board (Ireland)
FC	Frequency Control
GBA	Generic Bootstrapping Architecture
GBR	Guaranteed Bit Rate
IEEE	Institute of Electrical and Electronics Engineers
GOOSE	Generic Object Oriented Substation Events
HIL	Hardware-in-the-Loop
ICT	Information and Communication Technology
IOTA	Internet of Things Accelerator, Ericsson IoT platform
ISD	Inter-Site Distance
LV	Low Voltage
mmPr	Mismatch Probability
MMS	Manufacturing Message Specification
MQTT	Message Queue Telemetry Transport
MV	Medium Voltage
PLC	Power Line Communication
PLL	Phase-Locked Loop
PMU	Phase Measurement Unit
PTP	Precision Time Protocol
RAN	Radio Access Network
RES	Renewable Energy Source
RT-Sim	Real Time Simulator
RWTH	Rheinisch-Westfälische Technische Hochschule, University in Aachen
SPG	Small Power Generation
SSAU	Secondary Substation Automation Unit
SSC	Secondary-Secondary Control
SC	Secondary Control
SDU	Service Data Unit
R-SV	Routable Sampled Values
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment
URLLC	Ultra-Reliable and Low Latency Communications
VC	Voltage Control
vEPC	virtualised Evolved Packer Core
VM	Virtual Machine
QCI	QoS Class Identifier
QoS	Quality of Service