RESERVE

D4.5 v1.0

5G Extended functionality development to support voltage and frequency control

The research leading to these results has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 727481.

Project Name	RESERVE
Contractual Delivery Date:	30.09.2017
Actual Delivery Date:	30.09.2017
Contributors:	Robert Farac (EDD), Zain Mehdi (EDD), Miguel Ponce de Leon (WIT)
Workpackage:	WP4 – Pan European real time simulation infrastructure and live 5G testing platform
Security:	PU
Nature:	R
Version:	1.0
Total number of pages:	21

Abstract

This document describes the equipment that could be used to perform experiments on potential solutions proposed within the RESERVE project to support the frequency and voltage stabilisation techniques developed. The focus of this deliverable is on the Information and Communication Technology (ICT) components.

Keyword list

Information and Communication Technology, 5G, Long Term Evolution, Hardware in a loop, Renewable energy systems, Real-time simulator, Pan-European simulator

Executive summary

RESERVE is developing new techniques for controlling the stability of frequency and voltage in the scenarios for up to 100% Renewable Energy Sources (RES). The scenarios which were developed with the help of energy providers are described in deliverables D1.1 and D1.3 in which the ICT system requirements are collected as well.

Based on the scenarios and the ICT requirements described in D1.1 and D1.3, the general experiment types and the experimental lab setup are described in this deliverable. The experiments will be executed in two phases. In the first phase, a single power grid simulator will be connected to the communication infrastructure in a Hardware-In-the-Loop (HIL) test system. In the second phase, real time simulators at four locations in Europe will be interconnected building a pan-European simulation infrastructure.

A wide range of ICT equipment and technologies listed in this document including distributed cloud, state of the art prototype, will be provided for experiments. The experiments will be further discussed during the project.

The ICT components that could be used in experiments were identified in this deliverable. The individual ICT components are described in detail.

Authors

Partner	Name	Phone / Fax / e-mail
EDD		
	Zain Mehdi	Phone: +49-2407-5755121 e-mail: zain.mehdi@ericsson.com
	Dhruvin Patel	Phone: +49-2407-5751041 e-mail: dhruvin.patel@ericsson.com
	Robert Farac	Phone: +49-2407-5753714 e-mail: robert.farac@ericsson.com
WIT		
	Miguel Ponce de Leon	Phone: +353-51-302952 e-mail: miguelpdl@tssg.org

Table of contents

1. Introduction

Integration of Renewable Energy Systems (RES) will lead to high volatility in the energy systems, that will require the deployment of new voltage and frequency stabilisation techniques such as those being developed in WP2 and WP3 of the RESERVE project. The scenarios and techniques developed in *WP2* and *WP3*, will be supported by reliable and low latency communication networks.

In one of our scenarios in voltage control realising the Linear Swing Dynamics (LSD) and online impedance monitoring scheme on a large scale, a huge number of the sensors and actuators will be deployed in the field. These field devices will generate real-time measurements. To support such huge demands, next generation communication networks will need to support the deployment of a massive number of the devices as well as to provide reliable transport for critical data.

5G – the next generation mobile network with its new technology enablers can support these new voltage and frequency stabilisation techniques. This document explains, among the other ICT components, the new 5G based communication solution which supports the new voltage and frequency stabilisation techniques for up to 100% RES enabled power grid networks.

Ericsson has installed an LTE radio base station at the RWTH test laboratory for experiments that will be run in WP4. During the next two years of the project, an LTE narrow-band and a 5G-ready radio base stations will be available for the project with the support of core network in Ericsson Eurolab. This will enable running experiments on different mobile technologies for comparison purposes.

This document explains the experimental setup in the lab. The hardware-in-the-loop (HIL) setup will for example consist of a 5G-ready base station connected to the power grid real time simulator. In the scope of the RESERVE project, a live cellular network with upcoming 5G network concepts will be realised in the lab to investigate the new voltage and frequency control techniques being developed in RESERVE. Especially, as part of *Task 4.4*, a distributed cloud system, based on software defined network technology, is realised. The distributed cloud system is realised as a state of the art prototype that will be available for the experiments of the project. This will enable partners to deploy the new distributed voltage and frequency control techniques on the test infrastructure.

1.1 How to read this document

This document is the outcome of *Task 4.4*.

Before reading this document, we recommend you reading *D1.1 – Scenarios and Architectures for 100% RES* for the description of the scenarios in the project. It also describes the mobile communication concepts from high level to very basic level.

This document is also based on the ICT scenarios and requirements described in *D1.3 – Requirements placed on ICT for energy systems with up to 100% RES*.

The structure of this document is as follows:

Chapter 1 introduces you shortly to the topic of this deliverable, and describes the document structure.
Chapter 2 describes experiments that could be run on the available infrastructure.
Chapter 3 describes the phases in which experiments will be executed.
Chapter 4 describes ICT components that could be used in experiments, and estimates when they could be available.

2. Types of ICT experiments that can be run on the infrastructure

The new techniques for controlling the stability of the frequency and voltage in the scenarios for up to 100% RES are developed in the RESERVE project in WP1. In the D1.3, the relevant frequency and voltage scenarios are described, and the requirements on ICT systems are collected. Those new future power grid scenarios and the ICT requirements have been the base from which general types of experiments are proposed. The following list describes the general type of experiments that can be run on the infrastructure available. It is not a definitive exclusive list. The list can be modified, and the experiments will be discussed and described with in more details during the project.

- **Proof of Concept** (PoC) to determine whether the planned systems work. Often the interfering of protocols and system is not as straightforward as expected. Building the prototype in the lab to demonstrate functionality brings these problems to light.
- Packet throughput under normal traffic load and under radio network overload conditions can be observed and optimised using **Quality of Service** (QoS) features.
- **Different networks** can be compared for the same scenarios. E.g., using LTE, Narrowband IoT (NB-IoT), New Radio (NR) and Breakout Gateway (BR-GW).
- New **distributed architecture** can be implemented (using breakout box) and compared to centralised architecture.
- Connection of the lab infrastructure to **trial site** for tests (e.g., ESB trial site).
- **Future work**: The experiments to be run on the infrastructure will be defined as joint work among WP 2, 3, 4, and 5.

3. Test lab setup

The experiments listed in the previous section will be executed in two phases. In the first phase, the basic solution components, on which the basic scenarios will be executed, will be installed. In this first phase, the experiments will be run at the single location - Institute for Automation of Complex Power Systems (ACS) lab at the RWTH university in Aachen. In the second phase, the labs in four European countries will be interconnected, and the more complex scenarios will be tested.

Accordingly, the experiments will be run in the following phases (phases timeline shown in Figure 1):

Phase 1. Simulations performed on **the single real time simulator** and communications as Hardware in Loop, and

Phase 2. Simulations performed on **the Pan-European simulator** and communications as Hardware in Loop.

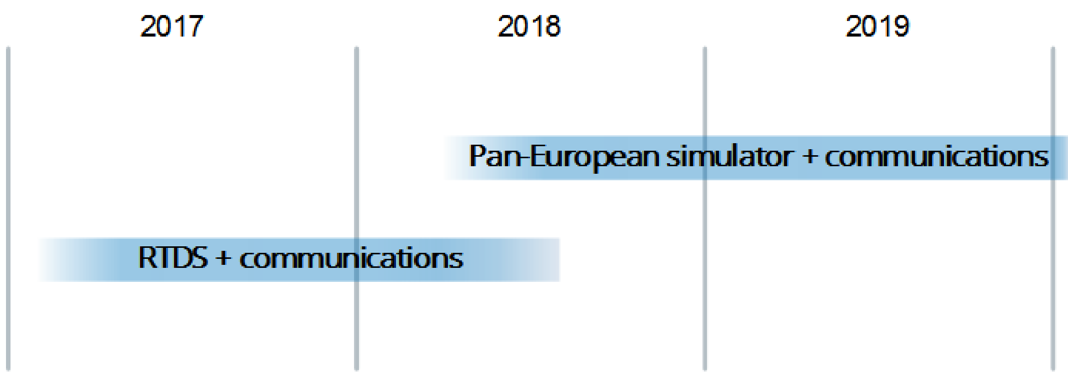

Figure 1: Test lab infrastructure phases timeline

3.1 Phase 1: Simulations performed on single real time simulator and communications

The test lab setup is configured at a state-of-the-art research facility at the RWTH university's ACS lab (see Figure 2). The environment of the test lab comprises power grids simulators and live communications infrastructures.

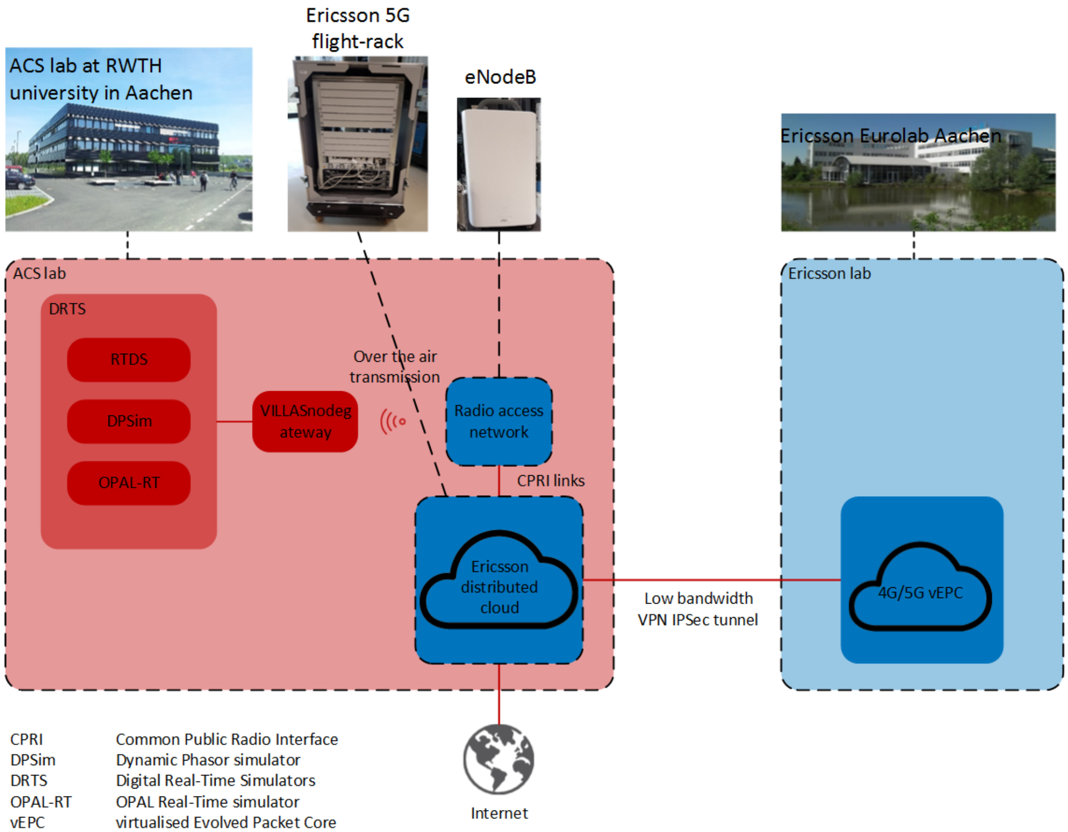

Figure 2: Phase 1 test lab setup

The ACS lab is equipped with several digital real-time simulators: RTDS, OPAL-RT, and DPsim. The group of the real-time simulators is referred to as Digital Real-Time Simulators (DRTS). RTDS is a real-time digital simulator with capacity of simulating more than 550 electrical nodes, second largest simulation installation in Europe. The OPAL-RT – real-time simulator has capacity of simulating 900 electrical nodes. The DPsim [D4.2] simulator is built in-house at the ACS lab.

DRTS is connected to the mobile communication network via VILLASnode gateway that is described in D1.4). The gateway has modems (transceiver) installed for the communication with the mobile infrastructures over the air. Test frequencies at low power are used for the testing.

The mobile communication network consists of the following major components: the radio access network, the distributed cloud and the mobile core network. The mobile network is located at two locations: the ACS lab and Ericsson lab that are connected over the Virtual Private Network (VPN). The radio access and the distributed cloud are located at the ACS lab while the core network is located at the Ericsson lab. The distributed cloud is deployed on the flight-rack on the several physical servers. The distributed cloud will host the voltage and frequency stabilisation algorithms for a wide range of experiments based on the input from WP1, 2 and 3. The core network enables authentication, mobility, and connection to other communication networks.

The essential distributed cloud enabler is Breakout Gateway (BR-GW), the state of the art prototype developed in the SUCCESS project [19]. This local gateway is based on Software Defined Networking (SDN) as an integral part of the 5G network architecture. BR-GW enables local data processing on decentralized computing nodes, as well as higher data speeds and lower latency as this solution bypasses the mobile core network.

The following ICT infrastructures are proposed to be used in the lab tests:

- DRTS with LTE flight-rack (this infrastructure is already installed and used),

- DRTS with distributed cloud,
- DRTS with Narrowband Internet of Things (NB-IoT), and
- DRTS with New Radio (NR) base station (5G technology).

3.2 Phase 2: Simulations performed on pan-European simulator and communications

The experiments in the second phase will be run on four locations, i.e., Romania (UPB), Ireland (WIT), Germany (RWTH) and Italy (POLITO) in the lab setup shown in Figure 3.

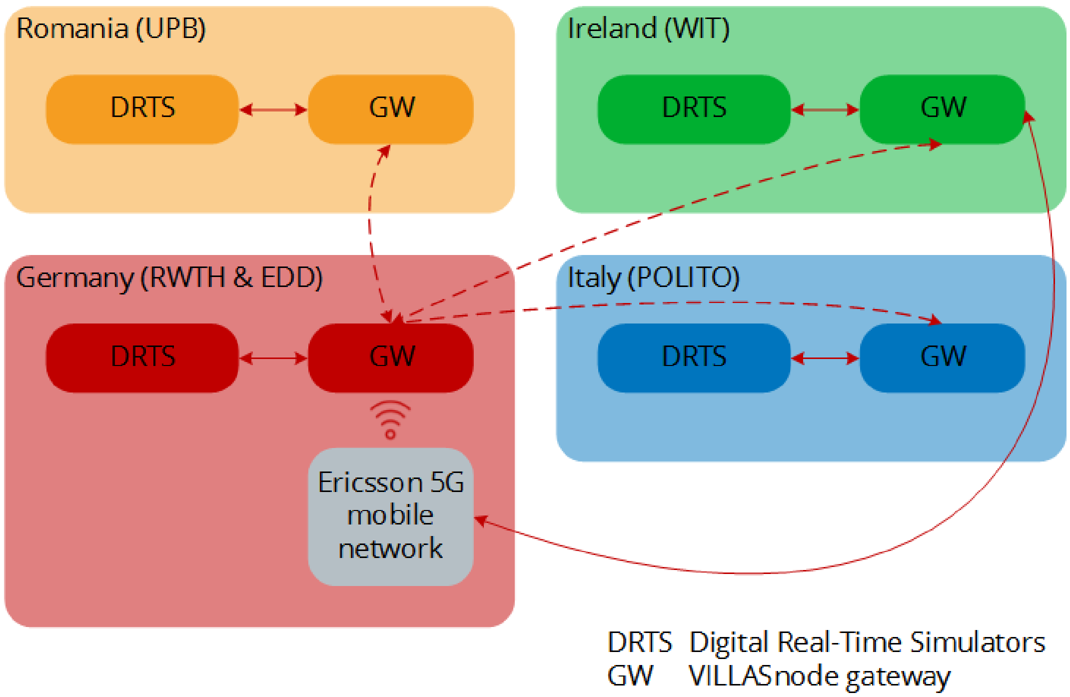

Figure 3: Phase 2 test lab setup

In this setup, the gateways have a double role: to connect DRTS with the flight-rack, and to interconnect remote gateways. Accordingly, the gateways will handle the following two types of the messages:

- Co-simulation interface messages, and
- Automation/control messages.

Co-simulation data will be exchanged solely between the simulators and routed over the VILLASnode gateways. These messages will only be used to perform the distributed simulation of the power system. The protocol carrying co-simulation data is a custom development which is simpler and similar to some of the existing interfaces of the DRTS. Co-simulation data is exchanged via UDP messages.

The automation/control messages use the IEC 61850-9-2 Sampled Values protocol an industry standard for substation automation. The IEC 61850 protocol is or will be used in the field to control inverters, circuit breakers, measurement collection and so on. In contrast, the co-simulation messages are not designed to be used in the field. They just enable co-simulation.

Only one flight-rack will be used in the test lab. However, a remote flight-rack can be used in experiments as non-stochastic delays via internet link can be extrapolated from the test results. In the operational setup, every location should be equipped with the collocated flight-rack.

As in the phase 1, different ICT infrastructures are proposed to be used in the lab tests, i.e.:

- Pan-European simulator with LTE flight-rack,
- Pan-European simulator with distributed cloud,
- Pan-European simulator with Narrowband Internet of Things (NB-IoT), and
- Pan-European simulator with New Radio (NR) base station (5G technology).

4. RESERVE ICT experimental infrastructure

Thorough analysis of the voltage and frequency scenarios and ICT requirements described in D1.1 and D1.3, together with the WP1 partners in a number of discussions has led to the identification of the ICT features and technics that could be used in experiments described in chapter 2.

The following ICT technologies and concepts are proposed accordingly:

- 4G components
    - Narrowband Internet of Things (NB-IoT)
    - Open Enterprise Connectivity (OEC)

- 5G components
    - Network slicing
    - Network Function Virtualisation (NFV)
    - Software-Defined Networking (SDN)
    - End-to-end security
    - New radio

- Distributed cloud
- End-to-end data integrity check
- Time synchronization with Precision Time Protocol (PTP)
- Communication between power grid simulators and mobile network using sampled values
- Exchange of messages on application layer in distributed systems using OpenFMB

4.1 4G (LTE evolution) technology components

4.1.1 Narrowband internet of things

The Narrowband IoT (NB-IoT) is an advancement in radio technology that supports a massive number of IoT devices. These devices run on low energy power and with less complex hardware. This technology also extends the coverage range substantially.

This technology is standardized in 3GPP Rel. 13 TS 36.201 [7]. The technology is designed for various industries and use-cases from factory automation to home sensors to power grid to health monitors.

NB-IoT is an enhancement in radio technology, and does not really depend on specific core network technology. It can operate in combination with other 3GPP technologies as well, such as GSM, CDMA.

In the case of NB-IoT the user-end modem devices are already available in the market. The technology is offering commercial large scale deployment for sensors, actuators, DERs in the field to connect with the cellular network instead of using short-range radio technologies or cables.

4.1.2 Open enterprise connectivity

Open Enterprise Connectivity (OEC) is a pre-configured and easily deployable small-scale LTE network. OEC architecture is shown in Figure 4.

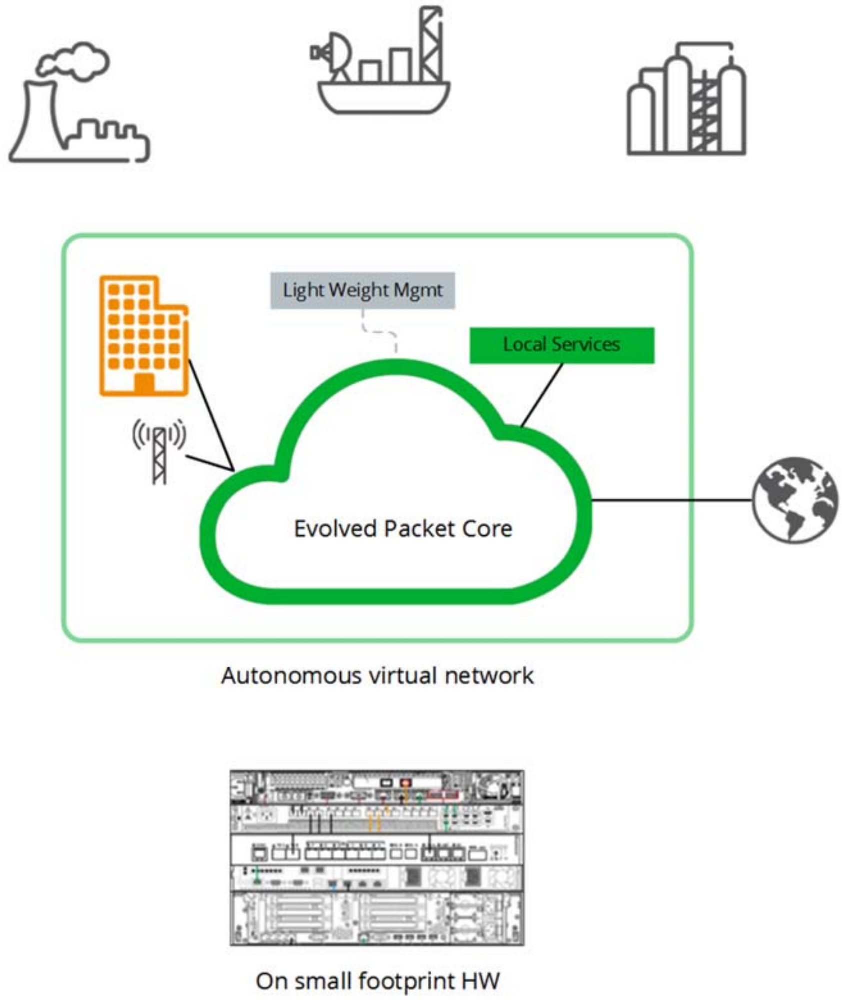

Figure 4 Enterprise private LTE network – dedicated core – private communications

This compact single physical unit consists of a fully working radio access network and core network. The solution is highly scalable. It can support multiple radio base stations and even add more nodes on core-network.

The Utilities can get the following benefits with this solution:

- Minimize radio interference,
- End-to-end reliability,
- Quality of Service,
- Critical data security,
- Managed Services,
- Full flexibility of the network applications, services, and
- Easy integration and scalable.

4.2 5G technology components

The requirements set by the new use-cases of voltage and frequency control scenarios has made communication companies think beyond the current network systems and develop the system with more focus on the industrial use-cases.

A smart grid network with up to 100% RES will have high volatility in energy generation, which will lead to the development of new real-time frequency and voltage stabilisation techniques. This will lead to a deployment of a huge number of sensors and actuators in the power grid network. The requirements are highly critical and 5G addresses these requirements by its new features and functions which will be part of the new functions which could be used in RESERVE roll-out architectures, such as those outlined in D1.3.

The components or the features as a future enhancement to LTE network which will be the part of 5G systems are the following: network slicing, network function virtualisation and software defined networking.

4.2.1 Network slicing

Network slicing gives flexibility in the network. It allows for the creation of multiple logical networks on top of one shared physical network infrastructure. In network slicing physical resources in mobile radio and core network are virtually divided to ensure the necessary priority for the specific performance requirement of the use-cases. This flexibility allows to address the cost, efficiency of the networks and requirements needed by the applications.

4.2.2 Network function virtualisation

Network function virtualisation (NFV) allows for separation of software from hardware. It also allows for the operation of data software applications at the network edge or core where ever needed, and provides for maximum scalability and reliability of the communication solution.

4.2.3 Software-defined networking

Software-Defined Networking (SDN) is based on the principle of separating the control plane and the data plane. It aims to provide a logically centralised network intelligence and a standardised interface for software development to control network resources and the flow of network traffic. Basic SDN components include the SDN controller, network elements and applications used to control network resources. The SDN controller interacts with applications via standardised Application Programming Interfaces (APIs) and on the other side with network elements with standard protocols such as OpenFlow [1]. The applications can implement network services like routing, security, and bandwidth management, with different behaviour for traffic in different flows, i.e., from different sources, responding to real-time demand changes in the network.

In the context of mobile communication technology, SDN can be realised as a software-based configuration of mobile transport and core network including capacity provisioning to enable the mobile network operator to configure the network depending on service requirements, and independent of the underlying physical and logical network architecture.

Especially as a part of the RESERVE project, the distributed cloud network concept is being developed, which is based on the Software-Defined Networking. The detailed development description of the distributed cloud is provided in a separate section.

4.2.4 End-to-end security

Current 4G cellular systems provide a high level of security and trustworthiness for users and operators. As 5G will act as a pillar for the Networked Society, additional aspects will be considered. To mention a few specific evolutionary technical topics that have been identified like: identity management, radio network security, flexible and scalable security architecture, energy efficient security and cloud security.

4.2.5 New radio

In order to support increased traffic capacity and to enable the transmission bandwidths needed to support very high data rates, 5G [17] will extend the range of frequencies used for mobile communication (Figure 5). This includes new spectrum below 6GHz, as well as spectrum in higher frequency bands up to 100GHz.

Besides targeting high-bandwidth and high-traffic-usage scenarios, the new flexible air interface will target also the new scenarios that involve mission-critical and real-time communications with extreme requirements in terms of latency and reliability.

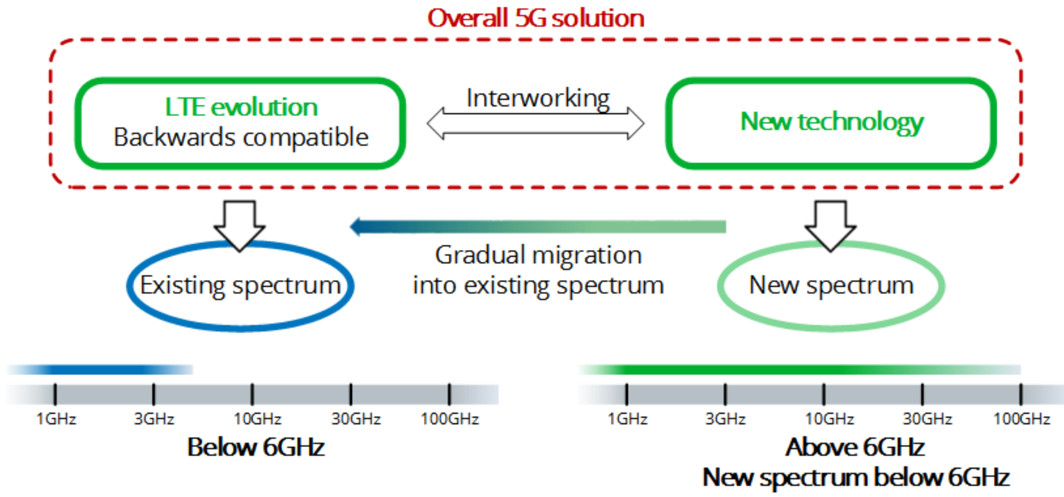

Figure 5 The overall 5G wireless-access solution consisting of LTE evolution and new technology

4.3 Distributed cloud functionality being developed for RESERVE experiments

The distributed cloud functionality is developed and implemented for the RESERVE project. The distributed cloud functionality that is based on SDN technology allows for the realisation of the data plane functions nearer to the radio access network. This functionality reduces the processing latency, and data remains local. Therefore, voltage and frequency control applications can be realised in distributed manner in the distributed cloud.

4.3.1 Motivation behind development of the RESERVE communication components

The scenarios in the RESERVE project with converters, synchroverters, rectifiers and real-time processing of the data being produced by the smart grid components has imposed stringent requirements in terms of latency, availability, and security on the ICT infrastructure. In general, three main requirements can be deduced based on the scenario description: **reliability, security, and tendency to react in very short time (in only few milliseconds).**

New upcoming mobile communication technology (5G) tends to focus on the development to satisfy such requirement for machine type communication. 5G with its upcoming technology enablers (as described in deliverable D1.1) seems to be a prominent candidate to support such new scenarios. RESERVE will develop network concepts based on upcoming 5G features and will investigate the performance in the live cellular network based HIL experiments.

The current mobile network technology does not support edge processing. However, in this project distributed cloud functionality is being developed using the key technology enablers of the 5G system. This local and distributed cloud system will be hosted near to the radio base station and it enables the local data processing to perform real time actions at the network edge much in order to satisfy real-time requirements of the RESERVE use-cases. This functionality will reduce the impact of local failures and response time of the actions taken by the algorithms.

4.3.2 Functional description of the distributed cloud system

The conceptual diagram of the distributed cloud is shown in Figure 6. The distributed cloud runs in a virtualized environment instead of physical node.

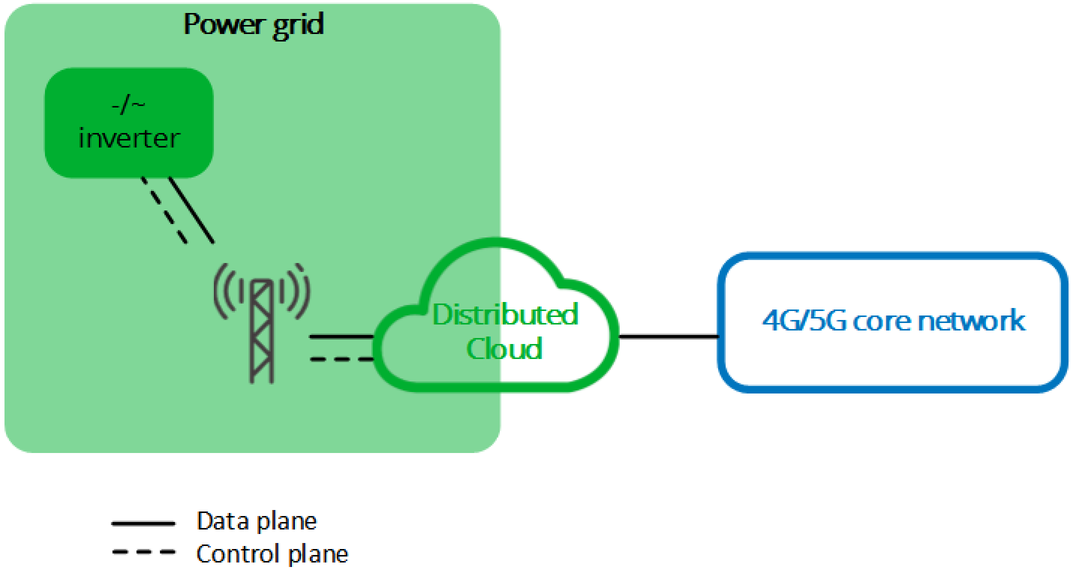

Figure 6: Distributed cloud

Local breakout

The local breakout is based on the principle of processing data plane traffic at the edge of power network. This functionality is realised by leveraging the Software Defined Network SDN technology. SDN allows dynamic configuration of the network. This will enable the data plane to locally terminate in the distributed cloud near to the radio base station rather than travelling to centralised core network located some distance away.

4.4 End-to-end data integrity check

Ericsson Data Centric Security (EDCS) [13] enables data integrity checking of the end to end information flow in any communication network. Smart meter critical data that are used for power grid state estimation or voltage control [8][9][10] could, if manipulated, disrupt the output of the power grid applications. Such attacks are commonly referred to as False Data Injection attacks. Data integrity of the measurements being communicated over any network should be protected and checked at the entry and exit points.

EDCS focuses on eliminating the security threats caused by data manipulation and authenticates measurement data used by above mentioned power grid applications. It uses a Keyless Signature [14], i.e., it uses a hash value to detect the manipulation of the data. The idea of the solution is to compute the hash value of the data that is being transmitted using a hashing algorithm such as SHA-256. The system will create a signature from the hash value which is sent, along with the data, to the application centre. The control centre can then verify that the data are correct and have not been tampered with.

The prototype solution for the integrity check based on EDCS developed in the SUCCESS project (Task 4.4 v2) can be reused in RESERVE with eventual modifications.

4.5 Time synchronisation with the precision time protocol over the 5G radio access

The Precision Time Protocol (PTP) is a time synchronisation protocol used for control systems, described in IEEE 1588- 2008. The PTP profile is standardised for frequency synchronisation by ITU (G.8265.1/Y.1365.1) in telecom. The main purpose of PTP is in the synchronization of clocks, phase, and frequency for geographically distributed systems. It comes at low cost, and it works over existing Ethernet or IP networks. PTP is mainly intended for wired packet based network like Ethernet, and allows sub-microsecond accuracy. Until now PTP is mainly used over UDP/IPv4.

Due to the missing hardware timestamping support as well as the inherently asymmetrical latency in the up/downlinks, the expected accuracy over the 4G testbed is in the range of 5-10 milliseconds. The PTP protocol [18] will be used for the synchronisation purposes in the experiments for frequency and voltage stability. Research is ongoing to improve the synchronization accuracy by using new 5G features.

4.6 Communication between power grid simulators and mobile network using sampled values

IEC 61850 [11][12] is a standard for vendor-agnostic engineering of the configuration of Intelligent Electronic Devices for electrical substation automation systems to be able to communicate with each other.

IEC 61850 protocol mapping profile is shown in Figure 7 [16].

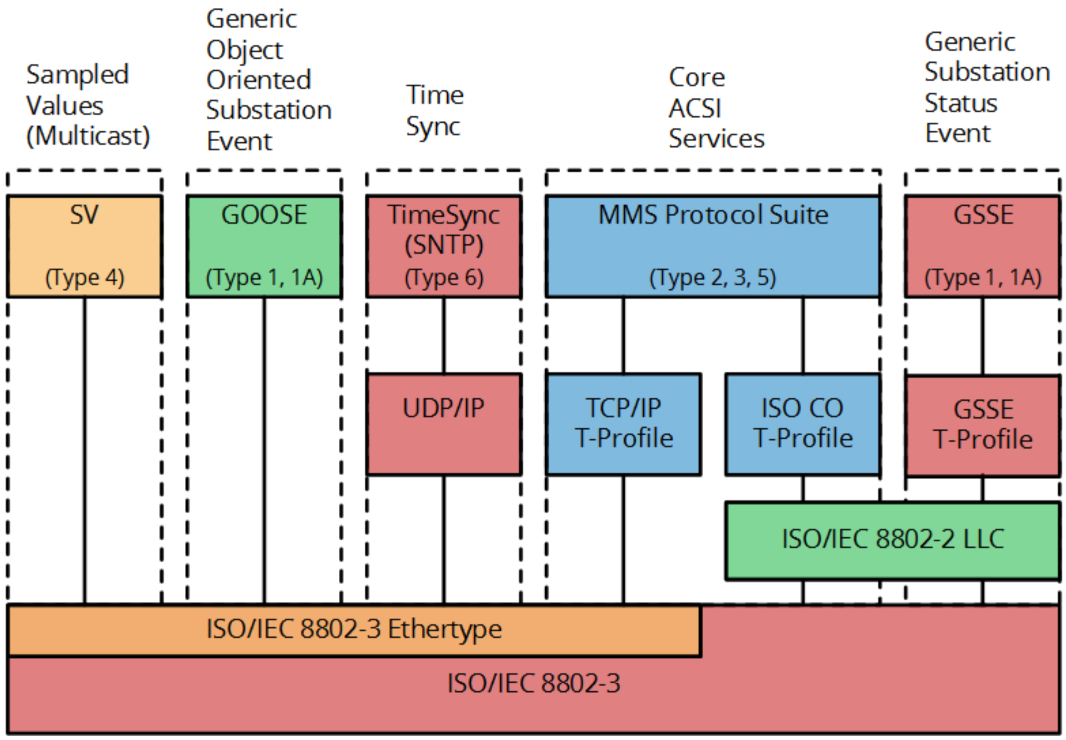

Figure 7 IEC 61850 protocol mapping profile

Sampled Values (SV) will be implemented for the communication between real time simulator gateway and the flight-rack. SV will be used for continuous exchange of the automation/control messages between devices and voltage/frequency control units that will run in the distributed cloud. The implementation of the SV protocol will not be straight forward because the IEC 61850 lower layer Ethernet protocol ISO/IEC 8802-3 is not supported in LTE. Therefore, two implementation options will be considered:

- ISO/IEC 8802-3 tunnelled through Generic Routing Encapsulation (GRE) [rfc1701], and
- The SV protocol will be modified in order to be routable (commonly referred to as R-SV [16]).

4.7 Exchange of messages on application layer in distributed systems using OpenFMB

For project experiments, OpenFMB will be used to support distributed processing and more efficiency.

Traditional power systems have relied on just a few sources of data information, in order to ascertain the status of the power system. Hence data transfer within power systems has primarily used slow transmission media with a communication model that is master/slave based. The power system protocols such as IEC 60870-5-101, ModBus and DNP3 are examples of this type of data transfer which has meant that all the data has gone to some central node for processing. While these protocols have been superseded by the more advanced protocol set of IEC 61850 MMS, GOOSE, and Sampled Values, with the introduction of new assets in the Smart Grid such as Advanced Metering Infrastructure (AMI), smart inverters, Phasor Measurement Units (PMUs), etc., there is now a large number of distributed data sources that can provide status information on the power network in quick and efficient way.

The traditional slower, centralised system is no longer an information communication architecture that can be used to process all of this data, and limits the possibilities of monitoring and controlling the capabilities of new grid based on 100% renewable energy systems.

The way forward is to put in place a distributed intelligence platform that can support peer-to-peer publish/subscribe messaging using widely available, economical internet technologies. This would mean that power system information no longer needs to go to a central system for decision making. The local data of monitoring/control units in the field can be made available to the power system software compute applications hosted on the distributed cloud near the eNodeB (base station). This can enhance the latency of decision making on local control for the units in coordination with knowledge from other operational data of the local power system.

One such new distributed intelligence platform for power systems is OpenFMB which uses a lightweight IoT protocol called MQTT (Message Queue Telemetry Transport). MQTT is highly bandwidth efficient and it uses a publish-subscribe model in contrast to MMS / Modbus protocols with their request-response paradigm. Another advantage of OpenFMB is the publish-subscribe model is that multiple subscribers can register to enrol for specific state variables within the messages being published by a monitoring/control units. Additionally, MQTT supports federation of multiple brokers which thus enables distributed support for peer-to-peer publish/subscribe messaging.

All in all, this means the DER/Customer Premise units in the field can publish their data to an OpenFMB messaging broker hosted on the distributed cloud, with a power system control software application subscribed to listen for those published messages, running on that same distributed cloud instance.

While there will be a future where AMI's, smart inverters and PMUs will have enough computing power to run a MQTT client on-board, in the near term and certainly in the time frame of the RESERVE project, consideration must be given to DER/Customer Premise units that already support protocols such as IEC 60870-5-101, Modbus, MMS IEC 61850, and Sampled Values IEC 61850.

4.7.1 OpenFMB functionality being developed for RESERVE experiments

The beauty of OpenFMB is that it already provides adapter support for the ModBus and DNP3 protocols. Within RESERVE, adapters for MMS IEC 61850, and Sampled Values IEC 61850 will be added to the intelligence platform.

Also of note Sampled Values IEC 61850 is a non-routed protocol, which relies on Ethernet layer 2 (ISO/IEC 8802-3) for its transfer of data. For RESERVE trials with OpenFMB and transfer over a 5G network requires a routable version of Sampled Values IEC 61850. The options are:

- Use Generic Routing Encapsulation (GRE) [rfc1701] for tunnelling ISO/IEC 8802.3 over IP, and
- Implement a IEC 61850-90-5 Routed-Sampled Value (R-SV) adaptor for OpenFMB as suggested by [4].

At the time of writing this report the option of routing using GRE tunnels will be explored first, and then the implementation of a IEC 61850-90-5 R-SV adaptor for OpenFMB will be considered.

4.8 ICT components availability

Figure 8 shows the estimated timeline of the availability of the ICT components and features that can be utilised for wide range of experiments at the RWTH lab. The timeline below is estimated and is not fixed. The components will be installed based on the availability.

An NB-IoT system can be provided in the following two variants:

- Upgrade currently installed LTE systems in the ACS test lab, and
- The separate HW as a ‘network in a box’ function.

5G features are introduced gradually, and accordingly they have being added gradually to the existing flight-rack. Some 5G features, as NFV, SDN and end-to-end security, are available from the beginning of the RESRVE project, and they are already or will be installed in the flight-rack for experiments purposes.

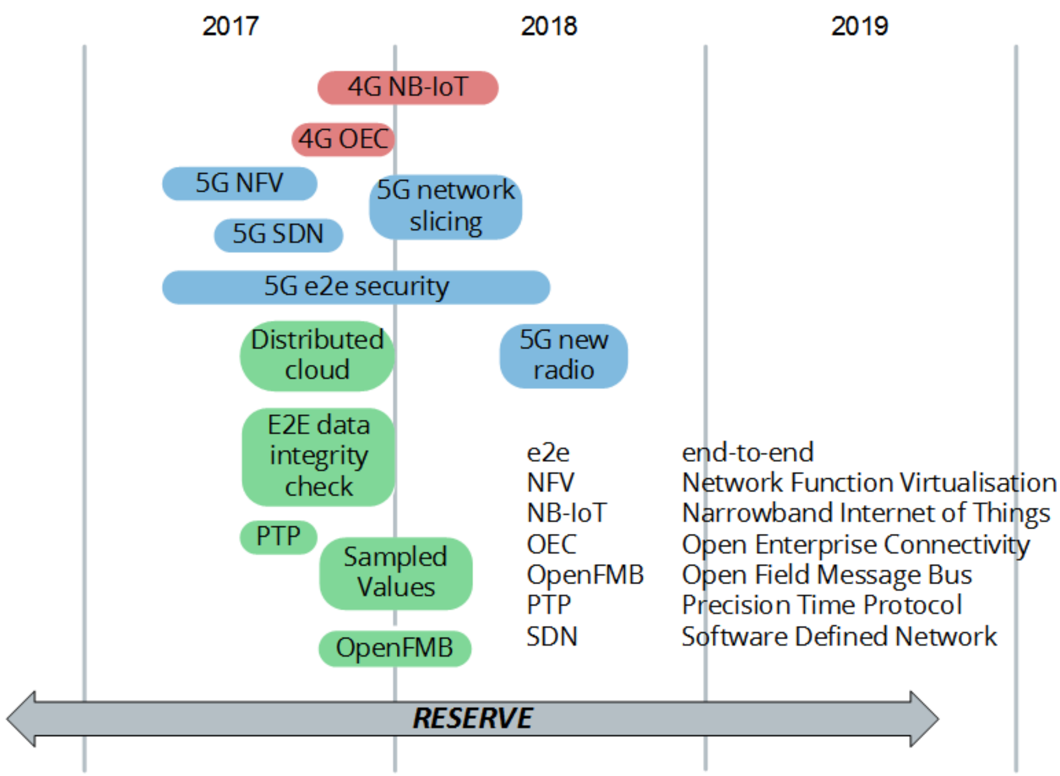

Figure 8 ICT components availability estimation

5. Conclusion

We have a wide range of equipment with a range of ICT facilities available for the usage in the experiments.

In the moment of writing, we have done the following:

- Architecture components have been selected and presented,
- LTE flight-rack is setup and configured at the ACS lab, and
- VILLASnode Gateway is equipped with LTE dongles.

In the next phase of the work, we will define which kind of experiments will be done.
As example, the next steps should be:

- Setup Virtual Machine (VM) on the distributed cloud for OpenFMB, and the control algorithms (algorithms used in frequency and voltage stability control),
- Test connectivity between VILLASnode Gateway and the flight-rack,
- Test performance of IEC 61850-9-2 SV over GRE over LTE, and
- Implement missing adapters/interfaces for IEC 61850-9-2 in OpenFMB and VILLASnode gateway.

6. References

1. Nick McKeown, Tom Anderson, Hari Balakrishnan, Guru Parulkar, Larry Peterson, Jennifer Rexford, Scott Shenker, and Jonathan Turner. 2008. OpenFlow: enabling innovation in campus networks. SIGCOMM Comput. Commun. Rev. 38, 2 (March 2008), 69-74. DOI=http://dx.doi.org/10.1145/1355734.1355746
2. Dahlman, Erik, Stefan Parkvall, and Johan Skold, “4G: LTE/LTE-advanced for mobile broadband”, Academic press, 2013.
3. Dohler, Mischa, and Takehiro Nakamura, “5G Mobile and Wireless Communications Technology”, Eds. Afif Osseiran, et al. Cambridge University Press, 2016.
4. Firouzi, Seyed Reza, Luigi Vanfretti, Albert Ruiz-Alvarez, Hossein Hooshyar, and Farhan Mahmood. "Interpreting and implementing IEC 61850-90-5 Routed-Sampled Value and Routed-GOOSE protocols for IEEE C37. 118.2 compliant wide-area synchrophasor data transfer." Electric Power Systems Research 144 (2017): 255-267.
5. http://www.opal-rt.com/wp-content/themes/enfold-opal/pdf/L00161_0473.pdf
6. http://www.ee.columbia.edu/~roger/ShmooCon_talk_final_01162016.pdf
7. 3rd Generation Partnership Project “Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description” – TS 36.201.
8. Angioni, Andrea, et al. "Coordinated voltage control in distribution grids with LTE based communication infrastructure”, Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on. IEEE, 2015.
9. Pau, Marco, et al. "Low voltage system state estimation based on smart metering infrastructure”, Applied Measurements for Power Systems (AMPS), 2016 IEEE International Workshop on. IEEE, 2016.
10. Teixeira, André, Dán, György, Sandberg, Henrik, Berthier, Robin, Bobba, Rakesh B. and Valdes, Alfonso, “Security of Smart Distribution Grids: Data Integrity Attacks on Integrated Volt/VAR Control and Countermeasures',' *in Proc. of American Control Conference (ACC), Jun. 2014*
11. https://en.wikipedia.org/wiki/IEC_61850
12. http://seclab.web.cs.illinois.edu/wp-content/uploads/2011/03/iec61850-intro.pdf
13. https://www.ericsson.com/ourportfolio/it-and-cloud-products/data-centric-security?nav=productcategory020%7Cfgb_101_0536
14. Keyless Signature Infrastructure® (KSI™) Technology - An Introduction to KSI Blockchain Technology and Its Benefits
15. IEC 61850 -Communication Networks and Systems in Substations: An Overview of Computer Science; Jianqing Zhangand Carl A. Gunter, University of Illinois at Urbana-Champaign
16. Interpreting and implementing IEC 61850-90-5 Routed-Sampled Value and Routed-GOOSE protocols for IEEE C37.118.2 compliant wide-area synchrophasor data transfer
17. Ericsson white paper: 5G radio access
18. IEC/IEEE 61850-9-3
19. The SUCCESS project, deliverable D4.4: “Description of Available Components for SW Functions, Infrastructure and Related Documentation, V1”

7. List of abbreviations

ACS	Automation of Complex Power Systems
AMI	Advanced metering infrastructure
BR-GW	Breakout Gateway
CDMA	Code Division Multiple Access
DER	Distributed Energy Resources
DMS	Distribution Management System
DPsim	Dynamic Phasor simulator
DRTS	Digital Real-Time Simulator
DSO	Distribution System Operator
EDCS	Ericsson Data Centric Security
eNodeB	Evolved Node B
ERP	Enterprise Resource Planning
ESB	Electricity Supply Board
ETSI	European Telecommunications Standards Institute
GOOSE	Generic Object Oriented Substation Events
GRE	Generic Routing Encapsulation
GSM	Global System for Mobile Communications
GW	Gateway
HIL	Hardware In the Loop
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISO	International Organization for Standardisation
KPI	Key Performance Indicator
LSD	Linear Swing Dynamics
LV	Low Voltage
LSD	Linear Swing Dynamics
LTE	Long Term Evolution
MQTT	Message Queue Telemetry Transport
MV	Medium Voltage
NB-IoT	Narrowband Internet of Things
NFV	Network Function Virtualisation
NR	New Radio
OEC	Open Enterprise Connectivity
OpenFMB	Open Field Message Bus
PM	Project Manager
PMU	Phasor Measurement Unit
PoC	Proof of Concept
PTP	Precision Time Protocol
QoS	Quality of Service
RES	Renewable Energy Sources
R-SV	Routed-Sampled Value
RTDS	Real Time Digital Simulator
RWTH	Rheinisch-Westfälische Technische Hochschule
SDN	Software Defined Networks
SME	Small & Medium Enterprise
SS	Secondary Substation
SV	Sampled Values
UE	User Equipment
VPN	Virtual Private Network
VPP	Virtual Power Plant
WP	Work Package