RESERVE

D4.6 v1.0

5G Extended Functionality Integration and Testing in Pan-European Simulation Infrastructure

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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 provides an analysis of the power network protocols performance tests on a 5G-ready and a 5G-prototype mobile network under extreme conditions like maximal message transmission rate.

The tests conducted on the 5G-prototype test system showed significant lower latency in comparison to 5G-ready test system.

Keyword list:

power simulation scenario, LTE, 5G, 5G-ready system, 5G-prototype system, VILLASnode, network code

Executive Summary

Information and Communication Technology (ICT) tests have been executed on three test systems: 5G-ready system, a 5G-prototype system and an Ethernet test system that has been used as a baseline. 5G-ready and 5G-prototype test systems were used to conduct tests to compare the performance of the protocols on 5G radio access with 4G radio access. In all test setups, VILLASnode gateway software (cf. Deliverable 4.1) is utilised for power traffic generation and as measurement tool. Tests have been conducted at two locations, the laboratories at the Institute for Automation of Complex Power Systems (ACS) in RWTH University, and Ericsson in Aachen.

ICT tests have been chosen to test the most relevant parameters like latency and reliability that are most relevant for power simulation scenarios considered in RESERVE. Advanced power protocols based on IEC 61850 standard like Sampled Values (SV) [3], Message Queue Telemetry Transport (MQTT) [2], and Advanced Message Queuing Protocol (AMQP) [1] have been tested in 5G and Ethernet systems. The protocols behaviour of the power protocols for wide range of message rates and sizes has been observed. As a result, communication network performance indicators, such as latency and packet loss, are provided for different power network protocols under a wide range of conditions.

The tests conducted on the 5G-prototype test system showed significant lower latency comparing to the tests on the 5G-ready test system. Some of the protocols showed lower latency compromising the delivery of the messages and vice versa.

The tests results showed that the functional requirements, performance requirements and security requirements for the voltage and frequency control scenarios defined in RESERVE can be achieved.

Future work should take into consideration a deeper analysis of the protocols and their implementation to gain further insights into latency trends for varying transmission rates. The influence of the underlying transport layer protocols should also be taken into consideration.

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1. Introduction

1.1 Aim of Task 4.5

The goal of Task 4.5 is to secure that the RE-SERVE communications solutions can be handed-over to WP5 for use case testing. It comprises of the integration of the created gateway elements and application software elements with the 5G communication infrastructure. Once the configuration has been integrated, tested and optimised, the 5G ICT solutions can be used for verification of the voltage and frequency control scenarios developed for simulation in WP 5.

1.2 Objectives and outline of the deliverable

RESERVE has specified several power simulation scenario tests in work packages 2, 3, 4 and 5, where 5G-based ICT will be used for the control of frequency and voltage in power networks as the percentage of Renewable Energy Sources (RES) generation increases towards 100%. In parallel, ICT test infrastructures and the test cases have been defined and described in D5.8.

ICT tests have been executed based on the ICT test cases in the laboratory. The tests have been conducted on two different 5G test systems as well as on an Ethernet test system. The reason for conducting experiments on two different 5G test systems was that one was using 4G radio access which is commercially available in the market and will be working with 5G core as well for at least a decade. The 5G-prototype test system is the state-of-the art technology and not yet available as a commercial product.

Some tests have not been conducted because they need to be run on the integrated communication and power network test system, which was not available as a test system before the preparation of this deliverble. Those tests are planned to be conducted in WP5 and reported in D5.9.

1.3 How to read this document

This deliverable is closely linked to D4.5 and D5.8.

Deliverable D4.5 lists 5G and ICT components used in the ICT tests. It also describes the project test plan and the test lab setup.

Deliverable D5.8 provides detailed description of the 5G-ready system test lab and the ICT test cases.

Deliverable D6.1 lists existing and new network codes considered in RESERVE.

Deliverables D2.2, D3.2, D4.4 and D5.6 list offline and online voltage and frequency simulation scenarios that were used as a base during ICT tests selection.

Deliverable D4.6 (this document) describes evaluation of the ICT tests which are conducted on a 5G-ready as well as on a 5G-prototype version.

ICT tests that will be run on the integrated communication and power network system will be described in deliverable D5.9. In the combined test system, a private Long-Term Evolution (LTE) test system will be connected to the power network simulator via VILLASnode. Private LTE is referred to as Open Enterprise Connectivity (OEC) system in D4.5. The results of the ICT tests described in D4.6 will be used as a reference in D5.9.

Figure 1 illustrates the relationship between this document and existing and future deliverables in RESERVE.

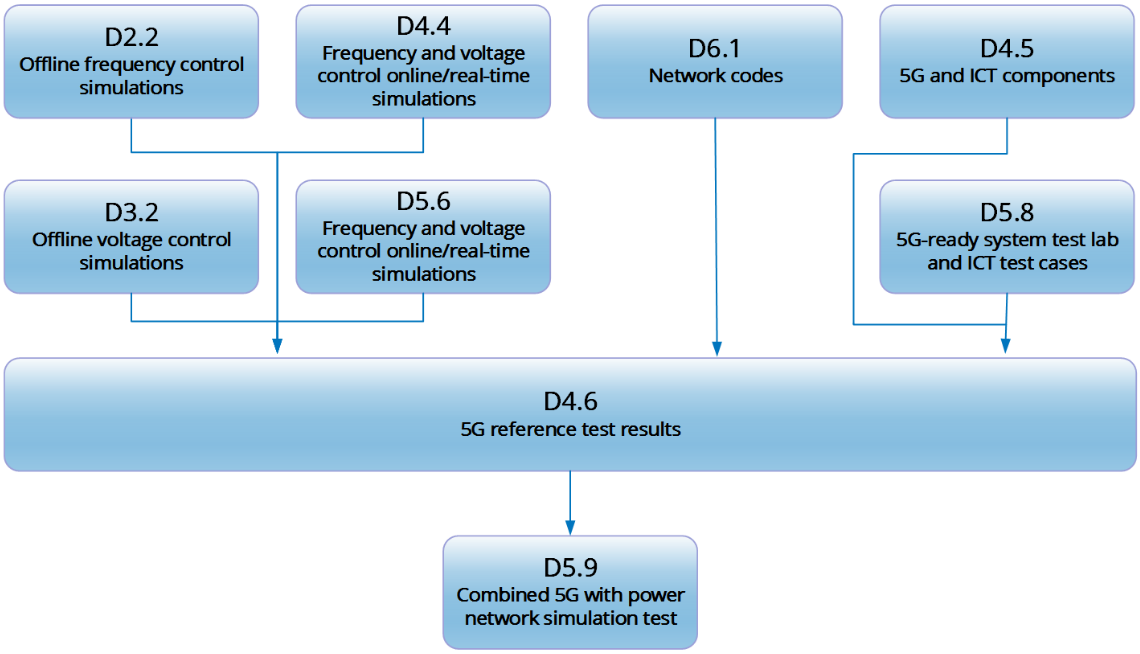

Figure 1: Relations between D4.6 and other deliverables

1.4 Structure of the deliverable

In Chapter 2, ICT test scenarios are selected in order to verify 5G communication parameters that are critical for the frequency and voltage stability scenarios. Furthermore, the power network protocols that are most relevant for frequency and voltage scenarios are chosen. In Chapter 3, test systems infrastructures and test methodology are described. Chapter 4 describes results of the tests conducted in the test systems, conclusions derived from the test results, and proposes future tests. Efficiency of the power protocols is compared. Chapter 5 shows implications of the conducted ICT tests for RESERVE project. Finally, conclusions of the work done in this deliverable are described in Chapter 6.

2. Selection of relevant ICT tests

The ICT tests have been chosen carefully to verify 5G communication parameters that are the most relevant for the frequency and voltage stability scenarios that are considered in RESERVE. The parameters tested in the 5G-prototype network were: user plane latency, reliability (packet loss), and maximum transmission (update) rate.

The relationship between the power network simulation scenarios and ICT tests is shown in Table 1. Power network simulation scenarios are classified in three groups: offline frequency simulation scenarios (Sf-A and Sf-B), offline voltage simulation scenarios (Sv-A and Sv-B), and online frequency and voltage simulation scenarios (RTS 1, 2 and 3; Real-Time Simulation).

#	ICT Test	Sf-A	Sf-B	Sv-A	Sv-B	RTS.1	RTS.2	RTS.3
1a	User plane latency in ideal traffic conditions		✓		✓			✓
1b	User plane latency in high traffic conditions	✓	✓			✓	✓	
2a	Communication reliability in ideal traffic conditions							
2b	Communication reliability in high traffic conditions	✓	✓	✓		✓	✓	
3	Maximum update/packet rate							
4	Communication outage – recoverability	✓	✓	✓	✓	✓	✓	✓
5	Communication outage – duration	✓	✓	✓	✓	✓	✓	✓
6	Corrupt / invalid data	✓	✓	✓		✓	✓	
7	Device time synchronization	✓	✓	✓	✓	✓	✓	✓

Table 1: Mapping between ICT tests and power simulation scenarios

In RESERVE the following top five Network Codes (NC) proposals from the large proposed list have been selected:

NC1 Requirements for new behaviour of RES inverters
NC2 Distribution system frequency control
NC3 System swing dynamics
NC4 Dynamic stability margins
NC5 Requirements on minimum system inertia

The relationship between the ICT tests and the top five network codes is shown in Table 2.

#	ICT Test	NC1	NC2	NC3	NC4	NC5
1a	User plane latency in ideal traffic conditions	✓		✓	✓	
1b	User plane latency in high traffic conditions	✓	✓	✓		✓
2a	Communication reliability in ideal traffic conditions					
2b	Communication reliability in high traffic conditions	✓	✓	✓	✓	✓

3	Maximum update/packet rate					
4	Communication outage – recoverability	✓	✓	✓	✓	✓
5	Communication outage – duration	✓	✓	✓	✓	✓
6	Corrupt / invalid data	✓	✓	✓	✓	✓
7	Device time synchronization	✓	✓	✓	✓	✓

Table 2: Mapping between ICT tests from D5.8 and 5 top network codes

2.1 Selection of the ICT tests conducted in the lab

In the scope of the RESERVE project, the performance of power network protocols has been tested on a 5G radio network to evaluate the influence of extreme conditions such as high message transmission rates and large message sizes. However, not all seven above listed ICT tests could be conducted with the available 5G equipment. Some tests, highlighted in orange colour in Table 3, such as communication outage duration, corrupt/invalid data, and device time synchronisation have not been conducted because these tests are not depending on 5G network performance. For instance, the probability that data transmitted over a 5G network will be corrupted by the network itself is very low, excluding cyber-attacks. However, those tests will be relevant in the power simulation scenario tests to validate the power system robustness (cf. Deliverable 5.9). Similarly, some of the tests were not performed because it was not possible to generate traffic congestion in the lab environment available at present for the 5G network system prototype available to the project in the period of the preparation of this deliverable.

In addition to previously selected ICT tests, a protocol efficiency test has been included in the test scope. This test has evaluated protocol overhead and has been used as a reference during comparison of test results of the tested network protocols.

#	ICT Test	Comment
1a	User plane latency in ideal traffic conditions	
1b	User plane latency in high traffic conditions	No traffic congestion could be created in lab
2a	Communication reliability in ideal traffic conditions	
2b	Communication reliability in high traffic conditions	No traffic congestion could be created in lab
3	Maximum update/packet rate	
4	Communication outage – recoverability	
5	Communication outage – duration	Test relevant for power scenario tests
6	Corrupt / invalid data	Test relevant for power scenario tests
7	Device time synchronization	Test relevant for power scenario tests
8	Protocol efficiency	

Table 3: ICT tests considered in RESERVE

The power network protocols behaviour has been tested in all above-listed tests. The following power network protocols that are most relevant for the frequency and voltage power network simulation scenarios, have been tested in the ICT tests:

- Sampled Values/IEC61850-9-2 (SV),

- Message Queue Telemetry Transport (MQTT), and
- Advanced Message Queuing Protocol (AMQP).

Focus of the ICT tests in RESERVE was on performance and comparison of the protocols behaviour in a wide range of extreme conditions such as high and low packet rate, and packet size in 5G and Ethernet test systems.

Figure 2 shows the protocol tests covered in each test system for the ICT test scenarios mentioned above.

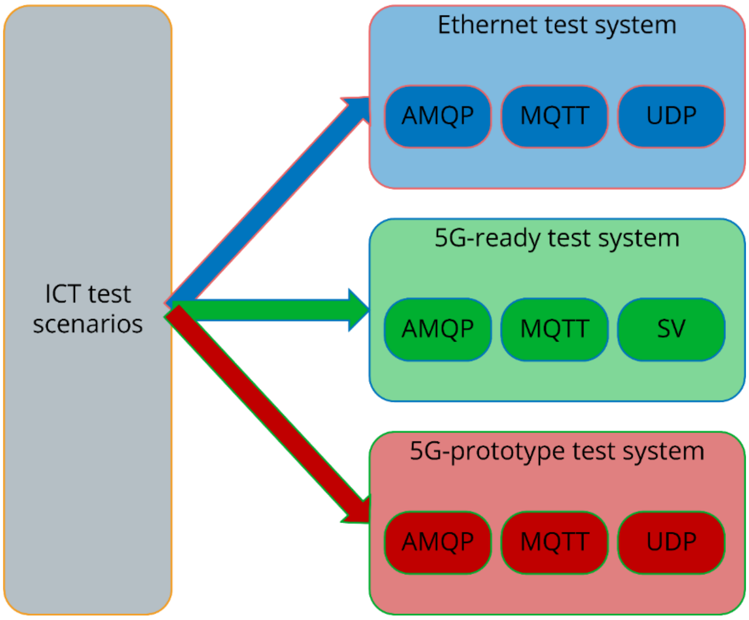

Figure 2: Protocols covered in test systems

3. Experimental infrastructure and methodology

This chapter contains a description of the experimental test infrastructure used to perform tests and discusses the various conditions and constraints which were taken into account while performing and analysing the tests.

3.1 Experimental infrastructure

In the project's RESERVE 5G ICT tests, two 5G-based systems have been utilised: a 5G-ready and a 5G-prototype system. The main difference between these systems is that the 5G-ready system relies on LTE radio access along with a 5G core network, while the 5G-prototype is using New Radio (NR) [16], the next generation radio access, without any core network. In addition to the 5G tests, a test on a local Ethernet network has been conducted to obtain a baseline for pure protocol characteristics without the influence of a radio system.

In each test system, VILLASnode (cf. Deliverable 4.1) has been used as a power traffic generator and traffic measurement tool on a dedicated PC. As a measurement tool, VILLASnode allows for logging the latency of each individual message. Deliverable 4.5 contains a detailed description of the ICT components and test cases. A detailed description of the measurement PC is provided in the annex (cf. Chapter A.1).

Figure 3 provides a common overview of the 5G-ready and the 5G-prototype test infrastructure. Both systems use a Radio Base Station (RBS) and a User Equipment (UE) to establish a radio link. The term "UE" refers to any device that allows a user to connect to the base station. VILLASnode is connected to both endpoints of the radio link (RBS and UE) in order to close the measurement loop and to log the latency. The following subsections contain a detailed description of all three test systems.

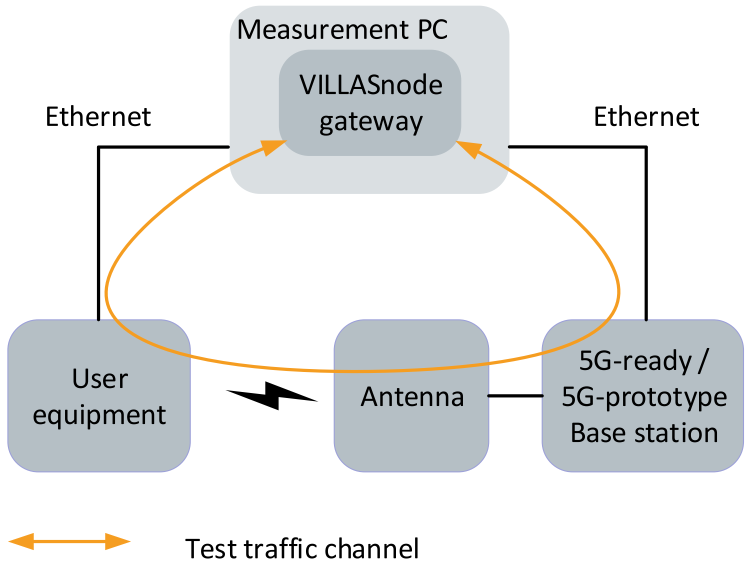

Figure 3: 5G system test infrastructure

3.1.1 5G-ready system test infrastructure

The 5G-ready system test infrastructure comprised of the following components:

- 5G-ready radio base station,
- 5G core network,
- User equipment, and
- VILLASnode software installed on a dedicated PC.

The 5G-ready test system has been composed of a 5G-ready radio base station set up in the laboratory at ACS in RWTH University and a 5G-ready core network running at Ericsson in Aachen. The 5G-ready base station has used an LTE-based radio access with a carrier frequency of 2.5 GHz. A commercial LTE dongle has been used as a user equipment. Test traffic has been generated by VILLASnode software gateway. The test traffic was flowing via the user equipment and the base station in both directions. At base station site, a breakout gateway deployed on the distributed cloud redirects the traffic to the measurement PC (cf. Deliverable 4.5).

3.1.2 5G-prototype system test infrastructure

The 5G-prototype system test infrastructure comprised of the following components:

- 5G-prototype radio base station,
- User equipment, and
- VILLASnode software installed on a dedicated PC.

The 5G-prototype system has been set up in the laboratory at Ericsson Eurolab in Aachen. When the experiments were conducted, suitable 5G user equipment chipsets were not yet available on the market. Therefore, a 5G-prototype user equipment installed in a rack has been used instead of a dongle.

Figure 4 shows the 5G-prototype user equipment and the 5G-prototype base station installed in flight-racks[1].

In the 5G-prototype system test infrastructure, NR-based radio access has been used at a carrier frequency of 3.5 GHz with beam forming. The 5G-prototype was an early adaption, made before the 5G standardization was completed, and does not yet provide the same features and performance we expect from future 5G systems. For instance, the packet loss on the radio link is relatively high. This loss is not directly visible in the test results because the tests have been conducted on the application layer and the packet loss happened on lower layers. However, the packet loss is indirectly reflected by increased packet latencies.

[1] 5G flight-rack is the term used in Ericsson to describe portable Ericsson 5G prototypes which are installed in a rack of a size which is easy to transport by aircraft.

Figure 4: 5G user equipment (left) and 5G-prototype base station (right) in flight-racks installed at E.ON Research Institute in RWTH, Aachen

3.1.3 Ethernet system test infrastructure

The Ethernet system test infrastructure comprised of the following:

- Ethernet switch and
- VILLASnode software installed on a dedicated PC.

The Ethernet system test has been set up in the laboratory at Ericsson and ACS in Aachen. It uses the same kind of measurement PC to create and log the VILLASnode traffic but instead of utilizing a radio link, the two Ethernet ports are directly connected to an Ethernet switch. Hence, the system allows for analysing pure protocol characteristics without the influence of any underlying radio link.

Figure 5 provides an overview of the explained Ethernet system test infrastructure.

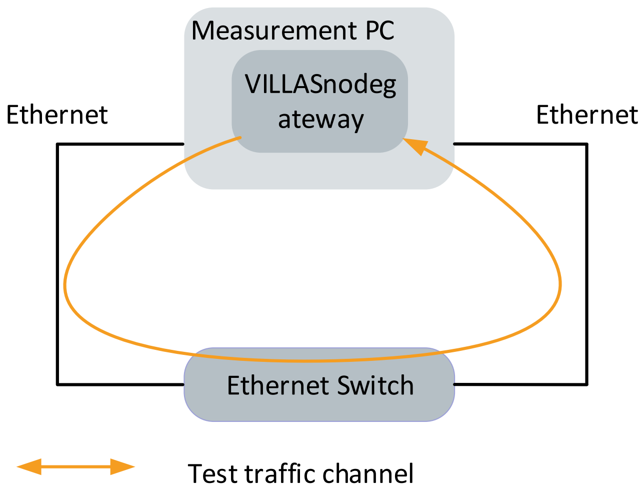

Figure 5: Ethernet system test infrastructure

3.2 Methodology

All experiments have been conducted on the 5G-ready system, the 5G-prototype system, and the Ethernet system as described in the previous section. The user plane latency experiments (test case 4.1.1 in D4.8) have been repeated for different transmission rates (10, 100, and 1000 messages per second). The number of data samples included in each message was increased (10 and 100 values per message). For the recoverability test case (4.1.4) the connection between the two VILLASnode entities was closed for 10 seconds. For the reliability test case (4.1.2), the results of the latency test have been reused to analyse the occurrence of packet loss. Deliverable 5.8 contains further descriptions of the applied test methodology.

As described in Chapter 3, VILLASnode has been used as a traffic generator (generating traffic in accordance to characteristics of power network measurement devices) and traffic measurement tool. To avoid side effects caused by the scheduler of the operating system, the VILLASnode software has been pinned exclusively to Central Processing Unit (CPU) cores.

Regarding the set-up of the general infrastructure and these experiments, the following constraints have been identified:

- No handover, device stationary and in fixed distance to one 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. For instance, the equipment may differ in processor, memory and discs performance, software versions, etc. In particular, the 5G-prototype would be replaced by a commercial solution.
- There was less interference on the radio interface in the test lab, and the devices had optical visibility to the antenna. In a real deployment, there will be obstacles in the environment of the air interface, including many reflected signals, each with a different time delay and phase, arrives at the receiver, etc.
- Packet loss in a real environment is certainly higher than in a test lab because we were not able to congest the networks.

Due to certain constraints in our 5G-system lab infrastructure, scalability testing was not performed. Nevertheless, the scalability of the proposed ICT architecture is a crucial aspect and must be validated in the future. For this reason, the protocol efficiency is tested which can be used to extrapolate the expected load on the network in large-scale setups.

The efficiency analysis on each of 7 test cases described in Chapter 2.1 has been performed for three different protocols:

- Advanced Messaging and Queuing Protocol (AMQP)
- MQ Telemetry Transport Protocol (MQTT)
- IEC 61850-9-2 Sampled Values (SV)

The AMQP and MQTT protocols do not specify the payload encoding. In order to compare them with the SV protocol, exemplary JavaScript Object Notation (JSON) [4] and Google Protobuf encodings [13] have been used.

All protocols were tested with the same test data which consists of a series 10,000 measurement points collected at a rate of 100 messages over 100 seconds. Each message contains 10 floating point values.

The efficiency is analysed by sending a series of messages over each protocol while dumping the network traffic with the *tcpdump* tool [14]. These tests were performed on the Ethernet system test infrastructure described in Chapter 3.1.3. In post processing, a network packet analyser named Wireshark [15], is used to calculate Protocol Hierarchy Statistics (PHS). The PHS dissects the network traffic and attributes the packet size to the individual sub-protocols of the communication stack. Additionally, the required bandwidth of a protocol can be estimated.

4. Test results

This chapter discusses the results of the conducted experiments on all three introduced test systems, including the Ethernet test system, the 5G-ready test system, and the 5G-prototype test system. The following subsections discuss the outcome of each experiment in more detail and present selected results of the experiments. Providing detailed results of all the conducted experiments would be out of scope for this deliverable. Annex chapter A.2 contains a detailed explanation of the used plots and how to read them.

4.1 Baseline system test

On this reference system, user place latencies in the range between 0.1 ms, for transmissions over User Datagram Protocol (UDP), and 0.9 ms for transmission over MQTT, were observed. In general, UDP based transmission achieved the lowest latency and seemed to be invariant against variations of the transmission rates. AMQP caused latencies in the range from 0.3 ms to 0.45 ms and showed a decreasing latency with increasing transmission rates. MQTT caused the highest latency in this test case in the range from 0.5 ms to 0.9 ms. For MQTT, the decreasing trend of the latency for increasing transmission rates is also perceptible but not as clear as for AMQP (cf.

Figure 6).

UDP caused the lowest latency due to the connection-less design of the protocol. In contrast, AMQP and MQTT caused higher latency due to the utilized publish-subscribe pattern and the underlaying connection-oriented TCP transport protocol. While it is advantageous that the connection-less UDP protocol showed lower latency because it does not re-transmit lost information, note that such a protocol cannot guarantee the delivery of individual packets. Especially when the network is congested, the probability for packet loss is very high. In contrast, protocols that rely on a connection-oriented transport protocol can guarantee the delivery of all packets. Hence, the protocol should be chosen considering the requirements of the application.

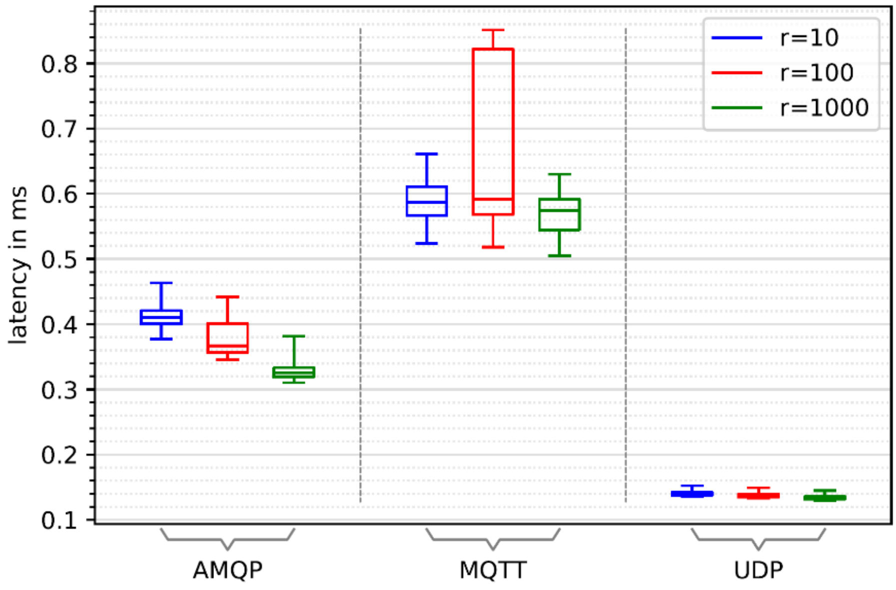

Figure 6: Latency boxplot for AMQP, MQTT, and UDP

4.2 5G-ready system test

On the 5G-ready system, experiments with three different protocols (AMQP, MQTT, and SV) were conducted.

Figure 7 shows a box plot comparing the latencies of measured AMQP and SV uplink latencies for transmission rates of 10, 100, and 1000 messages per second. Due to failures during the experiment, MQTT is not included in the plot and this part of the experiment is planned to be repeated in the next phase of the work.

The mean latency of the messages containing 10 values varies in the range between 15 ms and 25 ms. It is noteworthy that the mean latency tends to decrease with an increasing transmission rate. However, the variance of the latency is significantly higher for a transmission rate of 1000 due to retransmissions on the radio link.

Another measure for the system behaviour is the worst-case latency. AMQP and MQTT cause a worst-case latency that is five times higher than the worst-case latency of SV. These worst-case latencies fall in the range of 25 ms to 400 ms. This must be considered for critical applications that expect or require the messages to arrive within a predefined time window.

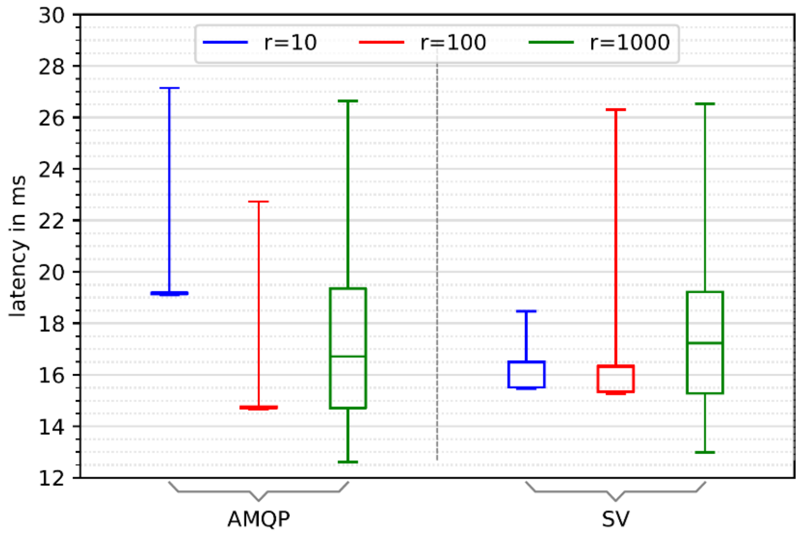

Figure 7: Uplink latency boxplot for AMQP and Sampled Values

In the scope of the experiment all tested protocols performed reliably regarding the caused packet loss, as none of the protocols caused any packet loss under ideal traffic conditions. Even SV as a connection-less protocol was not suffering from packet loss, because the network was not congested. For transmission rates above 1000 messages per second, however, SV started to suffer from packet loss. Furthermore, an increasing transmission rate causes an increase of the variance of the latency.

Experiments on the recoverability from connection loss revealed that the default configuration of the message brokers and clients for AMQP and MQTT did not allow a reliable automatic reconnection when the connection is lost. SV does recover from a connection loss since it is not connection-oriented. Therefore, all messages that have been transmitted during the downtime will be lost. It should be noted that this effect is dependent on the application and the respective configuration.

4.3 5G-prototype system test

On the 5G-prototype system, the same experiments as on the 5G-ready system have been repeated. The mean downlink latency for all protocols and rates varied in the range from 1.5 ms to 7 ms and the mean uplink latency was between 2.5 ms and 6.5 ms. Again, it strikes that the variance of the latency increases for a transmission rate of 1000 messages per second for all tested protocols.

Figure 8 provides an uplink latency comparison for different protocols on the 5G-prototype system.

The worst-case latency for all protocols is significantly lower than on the 5G-ready system. For instance, AMQP has caused latencies up to 380 ms on the 5G-ready system while it only caused a worst-case latency of 33 ms on the 5G-prototype system. Furthermore, the worst-case latency on the 5G-prototype system is similar to the worst-case latency on the Ethernet baseline system. Hence, these outliers seem to be caused by side-effects on the measurement computer and not by the radio network. Since the 5G-ready and the 5G-prototype experiments were conducted with different computers, this also explains the high difference in the worst-case latencies.

Furthermore, the experiments confirmed the behaviour of the protocols after a connection outage as described in the previous paragraph, as the connection-oriented protocols do not recover automatically.

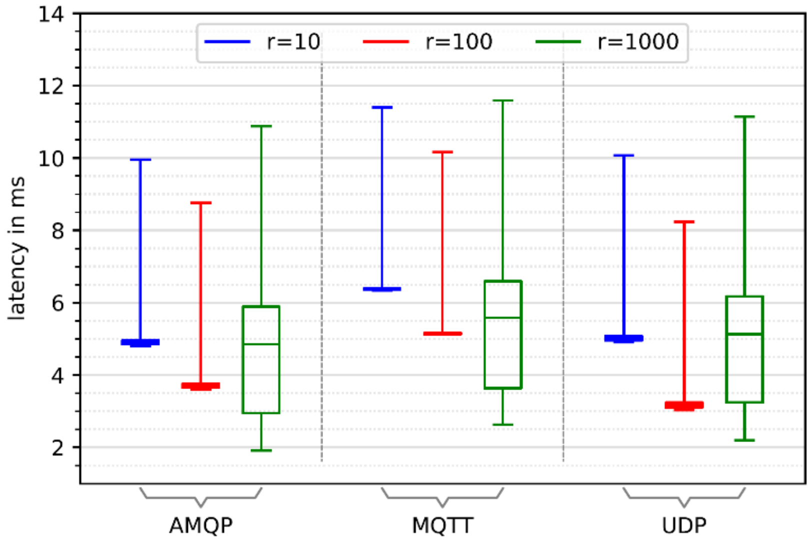

Figure 8: Uplink latency boxplot for AMQP, MQTT, and UDP

4.4 Protocol efficiency

Table 4 shows the total number of packets, the total traffic and the average bandwidth that was generated by each of the protocols under test. These measurements represent the possible network traffic generated by a single device.

	MQTT +JSON	AMQP +JSON	IEC 61850-9-2 Sampled Values	MQTT +Protobuf	AMQP +Protobuf
Total Packets	20017	34891	10000	20011	32159
Avg. Bandwidth [Kbit/s]	588.18	774.96	79.46	331.77	503.80
Total Traffic [MiB]	7.18	9.46	0.97	4.05	6.15

Table 4: Traffic statistics per device
(c=10000 measurements, t=100 secs, s=10 signals/measurement)

Figure 9 and Table 5 show the protocol hierarchy statistics per protocol. The data volume values in the table are averages per measurement. These results show that Sampled Values is the most lightweight protocol with only 98 bytes per measurement. In contrast, AMQP with JSON payloads sends almost a kilobyte of traffic per measurement which is caused mainly by the 70% protocol overhead of AMQP. Both AMQP and MQTT, in their tested implementation, rely on TCP which uses acknowledgement packets to ensure a reliable transport. These acknowledgments are reflected in packet counts, which are almost 2-3 times higher than for the AMQP and MQTT protocols.

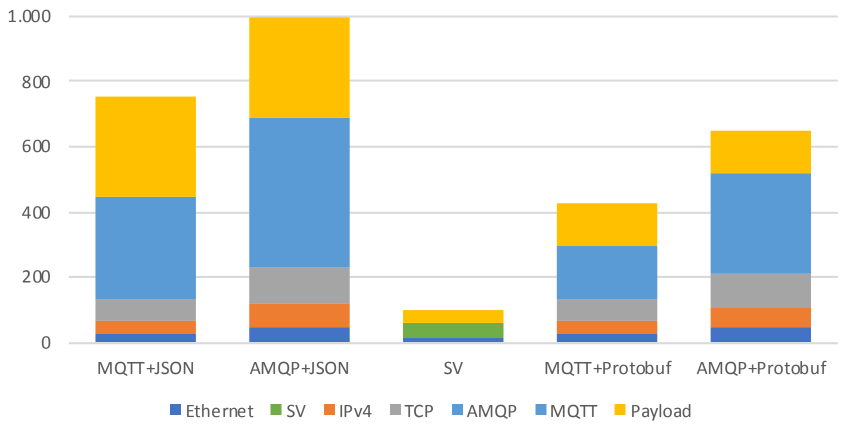

Figure 9: Average protocol hierarchy per measurement

	MQTT +JSON	AMQP +JSON	IEC 61850-9-2 Sampled Values	MQTT +Protobuf	AMQP +Protobuf
Ethernet	28 B	49 B	14 B	28 B	45 B
SV			44 B		
IPv4	40 B	70 B		40 B	64 B
TCP	64 B	112 B		64 B	103 B
AMQP		456 B			305 B
MQTT	316 B			164 B	
Payload	306 B	306 B	40 B	129 B	129 B
Total	**754 B**	**993 B**	**98 B**	**425 B**	**646 B**

Table 5: Average protocol hierarchy per measurement

4.5 Conclusions from the conducted tests

We observed that the 5G-ready system causes a latency in the range between 15 ms and 20 ms. On the 5G-prototype system, the latency is in the range between 1.5 ms and 11 ms. The series of tests provided results confirming our expectation that the 5G-prototype system shows latency between 5-10 ms. Comparing that to the 5G-ready system, an improvement for the latency is clearly demonstrated.

If we consider all results including the worst-case samples, then we observed a slightly different behaviour. On the 5G-ready testbed, the latency is in the range between 10 ms and 400 ms. On the contrary, on the 5G-prototype system the latency is in the range between 2 ms and 32 ms while on the Ethernet system the latency is in the range between 0.5 ms and 28 ms. This shows that the latency range on the 5G-prototype system and the Ethernet system are similar.

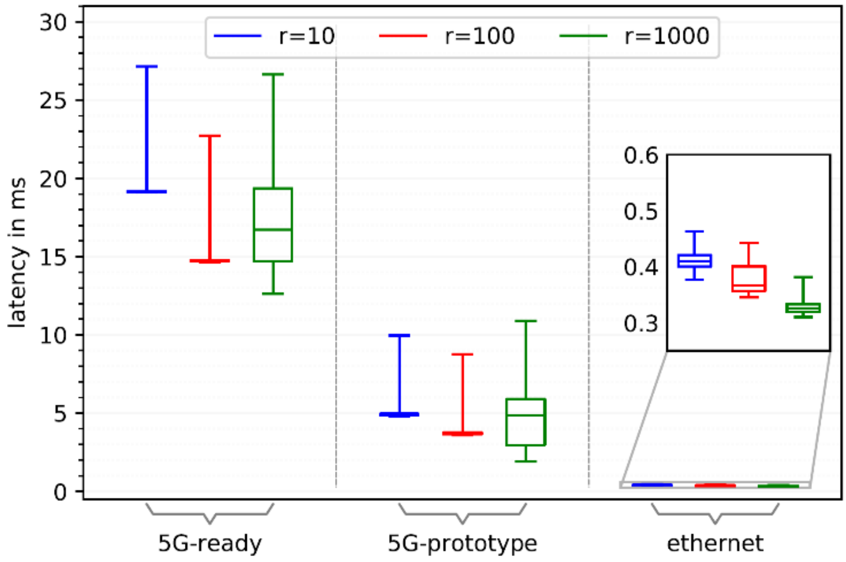

Figure 10: Comparison of AMQP uplink latencies on different systems

In most test cases, it is striking that MQTT results in a higher average latency than AMQP. This might be caused by internal implementation details of the broker. The worst-case latency shows a contrary tendency, resulting in higher worst-case latencies for AMQP.

Furthermore, the testing showed no packet loss for any of the protocols. AMQP and MQTT are using TCP as a reliable transport protocol. Hence, there was no visible packet loss on the application layer where we measured the arrival of the messages, but instead the link quality was indirectly represented by increasing variance of the latency. UDP and SV do not guarantee the delivery of the messages, but the load of the testbed networks was too low to cause any congestion-related packet loss.

The applications within the RESERVE project rely on periodical measurement data with high sampling rates. Furthermore, TCP-based protocols require more than twice the bandwidth and send more than twice the amount of network packets. In case of a congestion, TCP will automatically reduce the throughput which can be observed by increased user plane latency. In case of a network outage, TCP is likely to recover slower than connection-less protocols – if it even recovers at all - due to a risk for buffer and queue overload, these devices need to be emptied before normal operation can resume. Connection-less protocols such as Sampled Values will simply drop certain measurements and can therefore resume much faster. It has to be evaluated how the power system control methods will react in such situations. Typically for TCP, a lost packet will trigger an Automatic Repeat ReQuest (ARQ) by the sender which will send the lost packet again. Depending on the sending rate of the measurements, such a re-transmission might already be received too late to be of use by the power system control at the receiver side. If this is the case, a reliable transport like TCP is of little use for the power system control as performed in RESERVE and might only be interesting for monitoring which is not the focus of RESERVE.

4.6 Future work

Future work on ICT systems for dependable smart grids should provide a deeper analysis of the protocols and their implementations to gain further insights into the latency trends for varying transmission rates. This might allow for an optimization of the utilized transmission rates. The influence of the underlying transport layer protocols should also be taken into consideration.

Analysing the influences of lower layers of the operating systems and applications might also allow for further optimizations of the latency. For instance, the configuration of the buffers, like internal VILLASnode buffers and network interface buffers, could cause considerable side effects.

Therefore, future ICT tests should also cover various configurations of the underlaying lower communication layers in the application, the AMQP or MQTT clients, or the operating system itself.

Furthermore, the authors plan to repeat the described tests on a fourth test system, a private LTE network. That will also allow the team to repeat tests that failed during the original experiment due to technical issues.

The future test could validate if a 5G communication medium can support the Extensible Messaging Presence Protocol (XMPP) [3] technology suite, with XML Encoding Rule (XER) payloads [7]. XMPP protocol could be used for analysis and action in either the voltage or frequency control use cases.

5. Implications for RESERVE

When accessing the implications of the results achieved in this work on RESERVE, it is worth considering the affect these results will have on existing (but old) communication protocols & technologies, near future communication protocols & technologies and future communication protocols & technologies.

As highlighted in D4.5 for a long time, power systems have used a traditional data communications architecture known as “client – server”, leveraging old protocols such as IEC 60870-5-101 [4], ModBus [6] and DNP3 (Distributed Network Protocol) [11], in a centralised client-server data transfer model, using simple serial data transfer protocols.

The test results achieved during this work show that these classes of protocol can continue to be supported within the communication medium of 5G.

More recently, these old protocols have been superseded with the more advanced protocol set for power systems based on IEC 61850 MMS (Manufacturing Message Specification) [7], Generic Object Oriented Substation Events (GOOSE), and Sampled Values (SV) [3].

From an ICT perspective, the ICT requirements for the frequency and voltage control scenarios are delivered in deliverable D3.6. From the test results undertaken in this work, it can be seen that the functional requirements, performance requirements and security requirements can be achieved.

Finally, it should be noted that the new encoding concept, the use of an XML schema, is not exactly new in the ICT arena. JSON, the JavaScript Object Notation, is the data-interchange format most used today in the ICT industry and this has driven the RESERVE ICT team to also assess JSON broker-based technologies such as AMQP and MQTT.

The test results are highly relevant in this regard. Given that the ICT requirements set forth in the D2.4 and D3.6 deliverables require more distributed ICT architectures, with more compute analysis being carried out on the edge of the ICT network, then the use of 5G features with a communications medium with lower latency could provide further efficiencies for broker-based ICT systems (including AMQP and MQTT validated here) and even broker-less based ICT systems (such as nanomsg [9] and ZeroMQ [10] which were not validated here).

6. Conclusion

In the scope of this work package (WP 4, task 4.5), the authors took all possible power scenarios that are used in other work packages as input and identified relevant ICT scenarios. We conducted several experiments on a 5G-ready and a 5G-prototype testbed to investigate the behaviour of the entire ICT system under extreme conditions such as high transmission rates or connectivity outages. Furthermore, the authors tested the same scenarios for different protocols that are commonly used in the field of power network automation and simulation to investigate the impact of the used protocols. The experiments revealed that a new 5G-prototype system allowed for significantly lower latencies than the 5G-ready system.

Furthermore, the experiments revealed remarkable performance differences between all considered protocols. Some protocols achieved lower latencies while the delivery of the messages was not guaranteed. Other protocols guaranteed the delivery of the messages which can lead to increasing latencies. Hence, the final choice of the most suitable protocol depends on the requirements of the application regarding latency and reliability.

The experiments also revealed that an increasing transmission rate tends to decrease the latency. This effect might be caused by side effects of communication buffers and underlaying protocols. Further analysis of these effects is considered as future work.

7. References

[1] ISO/IEC 19464:2014 “Information technology -- Advanced Message Queuing Protocol (AMQP) v1.0 specification”

[2] ISO/IEC PRF 20922: “Information technology -- Message Queuing Telemetry Transport (MQTT) v3.1.1”

[3] IEC 61850-9-2: “Specific Communication Service Mapping (SCSM)-Sampled Values over ISO/IEC 8802-3, 2004.A”

[4] IEC 60870-5-101:2003 Telecontrol equipment and systems - Part 5-101: Transmission protocols - Companion standard for basic telecontrol tasks.

[5] RFC 8259 “The JavaScript Object Notation (JSON) Data Interchange Format” and ECMA-404 “The JSON Data Interchange Syntax”

[6] Modicon Modbus Protocol Reference Guide

[7] ISO/IEC 9506-1: “Industrial Automation systems - Manufacturing Message Specification - Part 1: Service Definition”, and ISO/IEC 9506-2: Industrial Automation systems - Manufacturing Message Specification - Part 2: Protocol Specification

[8] ITU-T X.693 | ISO/IEC 8825-4: “Information technology – ASN.1 encoding rules: XML Encoding Rules (XER)”

[9] https://nanomsg.org/index.html

[10] http://zeromq.org/

[11] IEC Std. 1815-2010: “1815-2010 - IEEE Standard for Electric Power Systems Communications -- Distributed Network Protocol (DNP3)”

[12] X.690: “Information technology – ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)”

[13] Protocol Buffers, https://developers.google.com/protocol-buffers/

[14] Manpage of tcpdump, https://www.tcpdump.org/manpages/tcpdump.1.html

[15] Wireshark official page, https://www.wireshark.org/

[16] TS 38.104, “Base station radio transmission and reception”

[17] IEC 61850-8-1:2011 Communication networks and systems for power utility automation - Part 8-1: Specific communication service mapping (SCSM) - Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3

8. List of Abbreviations

5G	5th Generation mobile communications system
AMQP	Advanced Message Queuing Protocol
ARQ	Automatic Repeat ReQuest
CPU	Central Processing Unit
DNP3	Distributed Network Protocol
DL	DownLink
GOOSE	Generic Object-Oriented Substation Events
ICT	Information and Communication Technology
JSON	JavaScript Object Notation
LTE	Long Term Evolution
MMS	Manufacturing Message Specification
NC	Network Code
MQTT	Message Queue Telemetry Transport
PHS	Protocol Hierarchy Statistics
RBS	Radio Base Station
RES	Renewable Energy Source
RTS	Real-Time Simulation
RWTH	Rheinisch-Westfälische Technische Hochschule, University in Aachen
SV	Sampled Values
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment
UL	UpLink
URLLC	Ultra-Reliable and Low Latency Communications
XER	XML Encoding Rule

Annex

A.1 Measurement PC - HW and SW configuration

The measurement PC used to run the experiments had the following configuration:

- CPU:
  - Intel Xeon CPU E5430 @ 2.66 GHz
  - 8 CPUs, 2 sockets, 4 cores per socket
- Operating System:
  - Linux 4.17.5-200.fc28.x86_64

VILLASnode software version:

- VILLASnode v0.6.2-6002d8f-Linux-x86_64-debug (built on May 15, 2018, 16:45:45)

MQTT/AMQP Broker:

- RabbitMQ Adapter 3.7.7

A.2 Reading the latency plots

In this report, grouped box-whisker plots are used to present the results of latency measurements. The plots either compare different protocols on one system or one protocol on different systems. For instance, in

Figure 11, the uplink latencies on the 5G-ready test system are grouped by two different protocols: AMQP and SV as indicated on the x-axis. For both groups, different message transmissions rates (r=10, 100, 1000) per second are considered and indicated by a colour scheme.

A box in the box-whisker plot is determined by the first and third quartile and therefore contains 50% of all values. The line within the box represents the mean value. The lines above and below the box are called whiskers or antennas. In the scope of this document, the whiskers indicate the 98th and the 2nd percentile, i.e., two percent of the data are neglected as outliers.

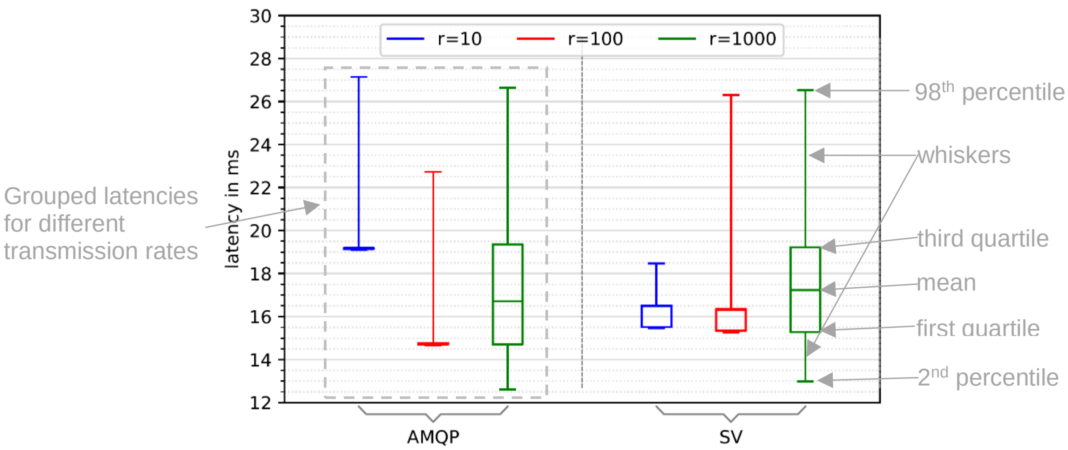

Figure 11 Exemplary box-whisker plot for uplink latency on 5G-ready system