SOGNO

D4.6 v1.0

Description of the integration and testing of the solution including the 5G based advanced communication

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Abstract
This deliverable provides an analysis of the SOGNO services performance tests on 4G and 5G mobile networks conducted in a laboratory infrastructure. Recommendations for radio access network optimisations are proposed based on the results of our tests, enabling improvements in the communications service latency performance of the SOGNO power network services.

Keyword list
5G, 4G, mobile radio networks, power distribution network automation services, SOGNO service, state estimation, power control, power quality evaluation, FLISR, power load prediction, power generation prediction services.

Disclaimer
All information provided reflects the status of the SOGNO project at the time of writing and may be subject to change.

Executive Summary

This report describes the outcome of set of laboratory tests whose **objective** was to define how to optimize 5G radio settings to provide the best latency performance in 5G networks supporting utility distribution automation use cases and, in particular, to estimate how well 5G could meet the requirements for latency for the Fault Location, Isolation and Service Restoration service (FLISR). Additionally, a set of tests using 4G (LTE) mobile networks were conducted to determine its general performance in supporting the SOGNO services.

The **services** defined and tested in field and laboratory trials in the SOGNO project comprise State Estimation, Power Quality evaluation, Load and Generation Prediction, Power Control and Fault Location, Isolation and Service Restoration services implemented as Cloud-hosted, model-based services, enhanced with machine learning algorithms, requiring very few low cost measurement points in the power network. The potential ICT requirements and 5G-based solutions for each of the SOGNO services were investigated in detail as a basis for our tests.

The **data streams** used to represent these SOGNO services in the mobile network test series reported here, were generated as synthetic data or generated by a power grid simulator. Power grid simulator data was used for tests of State Estimation, Power Quality evaluation, Load and Generation Prediction services. Synthetic data was generated to represent the typical data streams of a Fault Location, Isolation and Service Restoration and Power Control services. All data streams were tested under a range of 5G network optimizations. Typical utility **latency requirements** for the commercial use of the SOGNO power network services listed above were defined by SOGNO partners for each service.

Our **test configuration** included the deployment of the SOGNO services in an edge infrastructure in the 5G core network. We focused on testing a range of 5G radio network parameters which influence latency, focusing on the settings for the Modulation and Coding Scheme (MCS), Hybrid Automatic Repeat Request (HARQ), pre-scheduling and Physical Resource Block (PRB). The services tested are typical of the 5G 3GPP globally defined standard use case of Massive Machine Type Communication (mMTC). The tests reported in this document were conducted using an OPPO phone as the end user device.

The **tests results** reported in this deliverable show that, based on the use of the radio access network optimizations tested, **maximum improvements in latency** of between 44% and 81.25% were measured in the latency of 5G performance with the precise improvement depending on the service and the individual test case. Based on the results of our tests, we provide a set of **recommendations** on how to optimize the performance of 5G in supporting these services using a range of optimization parameters available in 5G non-standalone networks.

Our test results showed that both 4G and 5G **met the requirements** defined by SOGNO of latency under 1 second, for the SOGNO State Estimation service even without any optimization. The most challenging requirements of latency below 10 ms defined by SOGNO for the Fault Location, Isolation and Service Restoration service were only met in the 5G mobile network. The tests measured average round-trip-latencies below the requirement when optimizations on the 5G radio parameters were implemented.

Authors

Partner	Name	e-mail
Ericsson GmbH, Germany		
	Robert Farac	robert.farac@ericsson.com
	Zain Mehdi	zain.mehdi@ericsson.com
	Felix Maier	felix.maier@ericsson.com
	Onur Calik	onur.calik@ericsson.com
	Fiona Williams	fiona.williams@ericsson.com
RWTH Aachen University (ACS)		
	Marco Pau	mpau@eonerc.rwth-aachen.de
Ericsson Eesti AS, Estonia		
	Kristin Meriniit	kristin.meriniit@ericsson.com

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1. Introduction

The project *Service Oriented Grid for the Network of the Future (SOGNO)* is funded by the Work Program H2020-LCE-2017-SGS. It has officially started in January 2018 and has a duration of 30 months.

Nowadays, the energy systems based on power generation are being digitalized. Following digitalization, Distribution System Operators (DSO's) need their power grids to be more stable and monitorable, hence DSO's can have improved monitoring on their network and apply performance optimization remotely by utilizing automation. One of the aims of the SOGNO project is to make life of DSO's easier in the grid management by improving grid monitoring and stabilization providing cloud services. Improving the monitoring and visibility of the power network requires that new measurement devices are installed in the power network. The measurements made by the devices need to be communicated with the control centres of power utilities at regular intervals. The intervals between the measurements are constantly being reduced as the capabilities of the devices and the need for a detailed and accurate status of the power network increase. In coming years, SOGNO envisages that the SOGNO services could provide a close to real-time representation and control of the power network through near real-time, low latency communication of measurements to control centres, increasing the efficiency of operations of power networks and enabling them to use up of to 100% renewable volatile energy generation sources. The cost of providing cabled communications to large numbers of new devices deployed over wide geographical areas would be high. Mobile communication systems such as the already deployed 4G (LTE) and the new 5G networks now being deployed provide a cost-effective means to communicate with measurement devices and interest among power utilities in using mobile communication networks is constantly increasing.

For the SOGNO field trials, 4G (LTE) networks were used for communication with measurement devices in the field trials in Ireland and Romania as 5G is not yet deployed at the field trial locations. Laboratory tests using Ericsson 5G networks were conducted to investigate and optimize the performance which 5G networks could be expected to demonstrate in the field once the networks have been deployed on a large scale. 5G will enable more frequent reading of device measurements as it can provide lower latency, higher reliability communications than can be provided in 4G (LTE) mobile communication networks.

This deliverable reports on the performance of the 5G system in tests conducted in the laboratory to demonstrate that utilization of 5G meets the latency requirements of SOGNO services and based on tests of a range of settings of radio network parameters, it provides recommendations on how to optimize and reduce latency to a minimum. In this deliverable, SOGNO services and their requirements are introduced and detailed information about message generation of the SOGNO services is given. The test infrastructure established is explained in detail including the components used. Moreover, test cases are defined, and results of the tests conducted are interpreted. The tests performed aim to show how the latency of transmitted messages of SOGNO services is affected under different radio parameters.

1.1 Related project work

The report is based on the work done in task T4.5 of WP4. This task focused on integrating, testing and validating the service solution developed in T4.2, T4.3 and T4.4.

1.2 Objectives of the deliverable

The main objective of the report is to describe studies which verify that 5G mobile networks can meet the communications requirements of SOGNO services, to describe the ICT requirements of the SOGNO services and to describe the results of our investigations on how the 5G radio network can be optimized to meet more challenging requirements as the SOGNO services evolve in future years and require close to real-time communications links.

1.3 Outline of the deliverable

This report first describes the SOGNO services and their ICT requirements in chapter 2. Chapter 3 explains the data streams needed for the services and how they are generated for the tests. Chapter 4 covers the test configuration and the test infrastructure, including the components, the configured radio parameters and its limitations. The test cases and the results are presented in chapter 5. A conclusion of the report is given in chapter 6.

1.4 How to read this document

The document can be read on its own. Further details regarding the ICT requirements of SOGNO services are part of the deliverable D1.1 “Scenarios & Architectures for Stable and Secure Grid”.

2. The SOGNO services and their ICT context

This chapter provides an overview of the distribution automation power services which were researched, implemented and evaluated in field trials in Ireland, Romania, Germany and Estonia in the scope of the SOGNO project. As 5G was not available at the field trial locations, we conducted a series of tests of the SOGNO services with a live 5G network in a laboratory setting. Later in this report, we report on the results of these laboratory tests which investigated the optimization of the parameters of the 5G radio network in order to minimize the communications latency of the network as it supports the communication required by the SOGNO services.

2.1 The ICT context of the SOGNO services

The SOGNO services have been developed and optimized using machine learning techniques by SOGNO partners during the project, to provide early field trials and experimental results to validate their performance and that of the SOGNO vision of the near real-time visibility and control of the distribution power network enabled by 5G communications, illustrated in **Error! Reference source not found.** below.

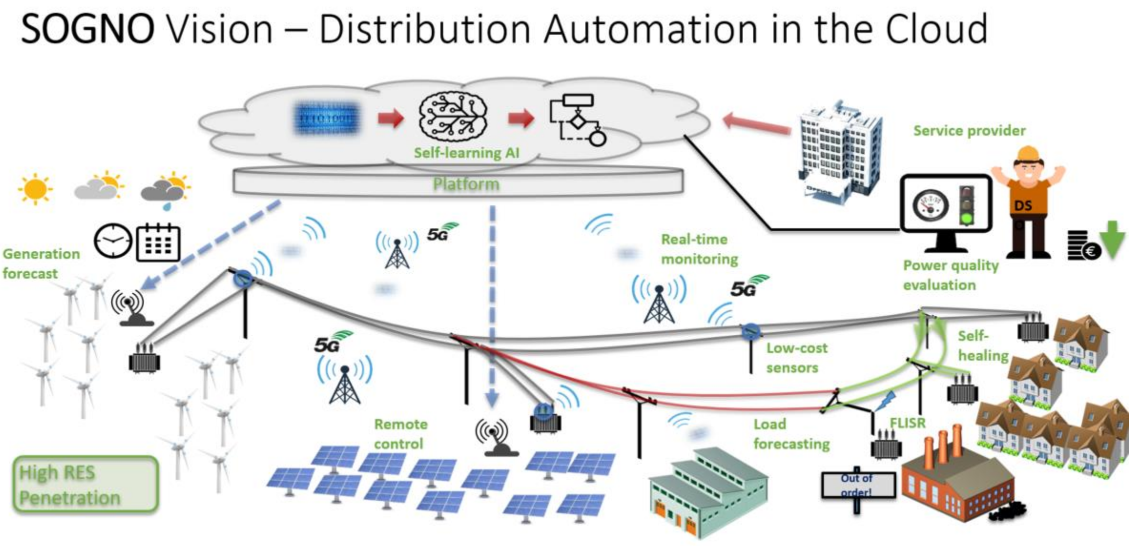

Figure 2.1 The SOGNO vision in an ICT context

The services defined in the scope of the SOGNO project are described in the following sub-sections. The SOGNO services can be hosted locally, in DSO clouds or in remotely located clouds. In 5G networks, services could be hosted on an edge infrastructure increasing the resilience of the power network to partial blackouts and reducing the latency of services.

2.2 The SOGNO distribution automation services

This sub-section provides a brief overview of the SOGNO services and the definition of the SOGNO project partners of the relevant latency requirements for each service. Further detail on the services can be found in a range of other deliverables of the SOGNO project available on the SOGNO website.

The **latency requirements** of the SOGNO services, described below, were determined in collaboration with project partners in the context of the short-term deployment of the SOGNO services in today's distribution power networks. As the capabilities of the services and control functionality evolve in power networks, the requirements of the services on latency is expected to increase as the percentage of volatile renewable power generation sources increases. 5G will be able to support the close to real-time operation of the SOGNO services in power networks.

The techniques used in mobile communication networks are specific to the direction of the communication. Communication from an end device, such as a sensor or smart phone, to a mobile network base station is termed “**uplink**” communication while communication from the base station to the device is termed “**downlink**” communication. Different techniques and resource parameters are assigned to the data stream being transmitted depending on whether it is uplink or downlink communication or a data stream supporting a service which requires both uplink and downlink communication. Some of the SOGNO services require only uplink communication (such as the State Estimation, Load and Generation Prediction and Power Quality evaluation services) and they are classified as **unidirectional power network services** in this report. The Power Control and FLISR services require both uplink and downlink communication and are classified as **bidirectional power network services** in this report. In our test series, we optimized the parameters of the 5G each for each of these two classes of power network services.

2.2.1 State Estimation (SE) service

The State Estimation service can be used to monitor the grid, visualize its performance and detect possible anomalies. In a full roll-out, the scalable design of State Estimation is based on a distributed architecture where results of LV (Low Voltage) SE can be used as input to MV (Medium Voltage) SE in order to improve the accuracy of the results. As a consequence, there are multiple steps before getting the results at MV level. This does not lead to a very strict requirement on latency, but still, if we want for example to push the execution rate of SE down to 1 second then we need to save time wherever we can to ensure that the overall SE process is done within that time. This includes designing computationally efficient algorithms but also, if possible, reducing the latency on the communication as much as possible.

Latency requirements: At this time, the SOGNO SE service was evaluated to require **maximum latencies of 1 s**, while messages are sent once per second.

2.2.2 Load and Generation Prediction (LGP) service

The Load Prediction (LP) service provides the power grid with future electricity demands, based on the historical information of customers’ power consumptions. On the other hand, the Generation Prediction (GP) service provides the power grid with the future generated power for example in a photovoltaic (PV) system based on the weather information, such as solar irradiance, temperature, humidity, etc. The information obtained by both LP and GP algorithms are utilized in power grid planning and operation to ensure stability and reliability.

This service uses the field measurements or the State Estimation data stream as input to the LGP algorithm.

Latency requirements: Due to the nature of these services, which process data offline and generate daily, hourly or quarter-hourly predictions, there are **no critical latency requirements**, and the expected data volume for both LP and GP is limited. In general, since the same monitoring units used for the SE service are also used to generate the data feeding the LP and GP services, the same latency requirements of SE can be used as a reference.

As the percentage of volatile renewable source energy generation in the power generation mix increases, such predictions will be made in near real-time to optimize the operation of the power grid and minimize CO_2 production and will require communications support using the full capabilities of 5G low latency services. Trends in this direction can already be observed in the operations of Virtual Power Plant operators, who optimize their predictions to optimize their power trading operations.

2.2.3 Power Quality Evaluation (PQE) service

The Power Quality Evaluation (PQE) service designed in the SOGNO project aims at providing the identification and monitoring of the most important phenomena commonly associated to power quality issues. In the SOGNO project, this is mainly achieved by means of the Advanced Power Measurement Unit (APMU), which is a low-cost device that is able to directly measure in the field some key parameters related to power quality, such as: phase voltages, phase current, harmonics, reactive power, power factor, unbalance factors (for both voltages and currents), neutral currents, etc. The information directly provided by the APMU can be optionally complemented by the results of State Estimation or by additional post-processing algorithms implemented in the Virtualized Substation (ViSA) cloud platform for the computation of other power quality indicators.

Latency requirements: The post-processing for data for this service is performed offline in the SOGNO field trials, so that there are **no critical latency requirements** for this service at present in the SOGNO project. A message frequency of up to 1 message per second is supported by the measurement device available for the field trials, but requirements up to 50 messages per second can be found in other scenarios using commercial Phasor Measurement Units (PMUs).

2.2.4 Fault Location Isolation and Service Restoration (FLISR) service

The FLISR service detects faults in the power grid and reacts immediately by sending a command to the corresponding location. It thereby improves the reliability of the grid as the cause of outages can be detected and corrected faster.

Apart from other services, FLISR does not need to receive periodical information from the power grid. Therefore, the most important requirement of FLISR service is that when a fault is detected on the power grid the message that can isolate faulty area must be sent immediately.

Latency requirements: The requirements of the FLISR service on latency are critical for the correct operation of the services in the SOGNO field trials. The total round-trip-time of messages should be in **milliseconds** (**less than 10 ms** is the constraint considered in the following tests).

In the SOGNO field trials, data for use in FLISR services was collected in the field to validate the correct operation of the SOGNO service in the laboratory. For health and safety reasons, live trials of the closed-automated loop of this service were not performed in the project field trials (namely, no switching command actions have been sent back to the field components).

2.2.5 Power Control (PC) service

Power Control will define and distribute target values for converters in the low and medium voltage grids, so that the right values of voltage can be maintained within limits at all times. The most important objective is to prevent over-voltages.

Latency requirements: In the use case considered in the SOGNO project, the power control messages should be received with a latency of under one second. In situations in which fully distributed and decentralized implementations of the power control algorithm are used, a much better latency of 0.1 s is required by this service (**20-30 ms** is deemed as a reasonable requirement).

2.3 Potential 5G ICT requirements for SOGNO services

This section describes ICT 5G requirements and solutions for SOGNO power services in commercial networks large scale deployments. The following SOGNO power services are considered: State Estimation, Fault Location Isolation and Service Restoration, Load and Generation Prediction, Power Quality Evaluation and Power Control.

The following set of the requirements are elaborated for each of SOGNO services: number of endpoints, latency, sampling rate, message volume, bandwidth, reliability, availability and security.

The **Number of Endpoints** shows total number of devices (sensors, actuators) with a connection to the communication network providing data from energy network.

The **Latency** describes the transmission time needed for a measurement or control signal to be sent from the sensor in the power grid to the control centre via communications network or vice-versa from the control centre to the actuator.

The **Sampling Rate** describes the number of messages per second that are transmitted between sensors and control centres (or vice versa).

The **Message Volume** indicates size of the message transmitted between sensor and control center including overhead for addressing, time stamps, authentication and authorisation, encryption, et al.

The **Bandwidth** describes the data rate per device depending on the sampling rate and the size of a data packet.

The **Reliability** describes the ability of a communication network to guarantee that messages reach their destination complete and uncorrupted and, in the order, they were sent.

The **Availability** represents maximal allowed communications system downtime.

The **Security** describes the need for the prevention of unauthorized access to telecommunications traffic.

2.3.1 ICT 5G requirements for State Estimation service

Communications (message transport) for State Estimation is uni-directional, i.e. uplink only, from the sensors to the control centre.

Number of endpoints

Measurement devices useful for SE purposes are usually placed in primary or secondary substations. The number of substations can vary from few per km^2 (in some cases even less than one per km^2) in rural networks to several tens (40-50) per km^2 in urban areas. The number of devices used for SE purposes strictly depends on the accuracy requirements of the DSOs and on their needs to monitor either only the MV grid or both the MV and LV grids. In general, for each monitored grid (MV or LV) only a few measurement devices (2-3) are already sufficient to enable a first level of monitoring of the grid, as proved through the field trials of the project presented in Deliverable D5.2. However, to achieve improved accuracy performance, a larger number of devices could be deployed by the DSOs (e.g. in specific scenarios of their interest), also following an evaluation of the tradeoffs between technical benefits and cost implications.

According to the above consideration, it is worth noting that different numbers of measurement installations can be found in different grid scenarios. They could vary per country and power grid according to the specific requirements of the DSOs. In general, however, it is reasonable to expect that in the next future, out of the total number of substations, only very few will be equipped with measurement instrumentation. This number will increase progressively over the years following the plans of DSOs for smartification and automation of their grids.

Latency

Latency is not very critical. At the moment state estimation is performed, in most of the cases, once every few minutes. But the requirements of distribution grids will push for a much faster rate in the next future, up to a second-level resolution, thus implying that also the measurement devices should be capable to transfer data with such time resolution. Accordingly, it is reasonable to define a maximum latency of the service in the order of 1 second.

Sampling rate

In the future, communicating one measurement per second can be easily forecasted, above all due to the spread of low-cost PMUs with second and sub-second level reporting rate.

Message volume

The total data volume amounts to approximately 1 KB per message and measurement point, including data for voltage, current, reactive power (Q), frequency, and RoCoF. The message size can slightly increase if additional power quality parameters are sent together with the measurements, but still it will remain in the order of few kilobytes.

Bandwidth (per device)

Maximal required bandwidth per device depends on the used protocol. If MQTT is used containing the headers (56 B fix) and payload with maximum 30 measurement values and the time stamp (20 B per value + 20 B for timestamp), the message size would be 676 B.

With the maximal sampling rate of 1 message per second, the bandwidth would be 676 Byte/s = 5.4 Kbps

Reliability

In a case where there will be only a few measurements on the field, the reliability of the data communication will be particularly important. In scenarios with many measurements, losing occasionally a measurement might not be so critical.

Availability

99.99% (four nines, meaning communications downtime per month of 4 minutes, is recommended).

Security

Security is critical since a large number of other management functions aimed at deciding how to operate the grid can depend on the SE service.

Table 2.1 shows ICT 5G requirements for the State Estimation service.

Table 2.1 ICT 5G requirements for State Estimation service

ICT 5G requirements	State Estimation service
Req-SE-endPoints	Few 10's per km^2 in urban areas
Req-SE-latency	Down to 1 second
Req-SE-sampleRate	Down to 1 measurement per second
Req-SE-volume	676 B per message
Req-SE-bandwidth	5.4 Kbps
Req-SE-reliability	Important if only few devices are available
Req-SE-availability	99.99% (communications downtime per month of 4 minutes)
Req-SE-security	Critical

2.3.1.1 Timescales and preconditions relevant to the commercial scale use of State Estimation service

Nowadays few larger DSOs, that are advanced with innovations and digitalisation of the grid or faced the issues characterised in the networks with high number of RES, implemented State Estimation service. If regulations will be changed, State Estimation will start to be implemented in many more grids. Deployment will probably be slower in the start because new measurement devices will have to be installed that will bring costs. However, it can be expected that the number of measurement devices will increase over time.

2.3.2 ICT 5G requirements for Fault Location Isolation and Service Restoration service (FLISR)

Number of endpoints

Usually it is in the range of few per km^2 or few in 10 km^2. Bi-directional communication is required to get switch status in the control center and to apply open or close control actions from the control centers to the switches.

Latency

For FLISR, time is an important aspect, as the power grid should be realigned swiftly after a disturbance in the LV or MV feeder. In many countries, the operator of a distribution grid has to pay penalties even for disturbances as short as three minutes but reducing the outage time is key also not to affect customers and critical infrastructures that need the power supply. Therefore, the total round-trip time of the FLISR service, including sensors, switches, data transmission and processing should be well below this limit.

Sampling rate

Messages should be sent every time a fault occurs.

Message volume

Data volume is not critical, as the number of switches in a LV grid is limited. Only the messages from the switches are needed to implement the FLISR service. Volume of each message should be also in the order of few KB as for the SE service.

Bandwidth (per device)

Not applicable since message will be sent only when fault occurs.

Reliability

FLISR is the most critical service in SOGNO. Therefore, maximum reliability of the communications system is recommended. If messages are lost, they must be sent again. It is essential to get all the messages related to FLISR.

Availability

99.999% (5 nines meaning communications downtime per month of 26 seconds) is recommended.

Security

It is essential that the data are transmitted in a secure way ensuring full data integrity because of automatic modification of grid edge settings; and, in this context, higher security than for monitoring services is required. Accordingly, maximum security level is requested.

Table 2.2 shows ICT 5G requirements for FLISR service.

Table 2.2 ICT 5G requirements for FLISR service

ICT 5G requirements	FLISR service
Req-FLISR-endPoints	Up to few per km^2
Req-FLISR-latency	Critical – few milliseconds, the lower the better

Req-FLISR-sampleRate	NA. Message should be sent when fault is happened
Req-FLISR-volume	<1 kB per message
Req-FLISR-bandwidth	NA. Message should be sent when fault is happened
Req-FLISR-reliability	Maximum reliability
Req-FLISR-availability	99.999% (communications downtime per month of 26 seconds)
Req-FLISR-security	Maximum security

2.3.2.1 Timescales and preconditions relevant to the commercial scale use of FLISR service

FLISR is the service that brings clear advantages that are known to DSOs. Accordingly, many DSOs have already deployed (or are planning to deploy) FLISR nowadays.

2.3.3 ICT 5G requirements for Load and Generation Prediction service

Load and generation prediction service does not take data from the field, but only the data stored in the database. Of course, the data stored in the database arrived at some point from the field.

Data transmission is based on the uplink direction only, when historic values for load and power were generated.

Number of endpoints

See State Estimation service for the number of substations where measurements that will be used for Load and Generation Prediction service can be collected. Additional measurements can arrive from generation plants and in this case the density of end points will become higher.

Latency

There are no critical latency requirements, since data are taken a posteriori from the database.

Sampling rate

See State Estimation service since the same data are likely to be used for Load and Generation Prediction service. Note that for Load and Generation Prediction service sampling rate of 1 measurement per minute is enough.

Message volume

See State Estimation service, since the same measurement device can be used also for Load and Generation Prediction service measurements collection.

Bandwidth (per device)

Maximal required bandwidth per device depends on the used protocol. If MQTT is used containing the headers (56 B fix) and payload with maximum 30 measurement values and the time stamp (20 B per value + 20 B for timestamp), the message size would be 676 B.

With the maximal sampling rate of 1 message per minute, the bandwidth would be 11.3 Byte/s = 90.1 bps = 0.09 Kbps

Reliability

Important but not critical. Prediction algorithms work also if there are some missing values, since there are procedures to replace them.

Availability

Not critical. 99.9% (3 nines meaning communications downtime per month of 43 minutes) or even more is acceptable.

Security

Important but not critical. If a few data are corrupted, it is not a big problem. Of course, if all the data of a certain period are wrong then also the prediction would be wrong. But in such scenario, there will be already other services that are more critical suffering from the bad data.

Table 2.3 shows ICT 5G requirements for the Load and Generation Prediction service.

Table 2.3 ICT 5G requirements for Load and Generation Prediction service

ICT 5G requirements	Load and Generation Prediction service
Req-LGP-endPoints	Few 10's per km^2 in urban areas or more
Req- LGP-latency	Not critical as data are taken from the database
Req- LGP-sampleRate	Down to 1 measurement per minute
Req- LGP-volume	676 B per message
Req- LGP-bandwidth	0.09 Kbps
Req- LGP-reliability	Important but not critical
Req-LGP-availability	99.9% (communications downtime per month of 43 minutes) or less
Req- LGP-security	Important but not critical

2.3.3.1 Timescales and preconditions relevant to the commercial scale use of Load and Generation Prediction service

Load and Generation Prediction is offline service and therefore is not interesting to be considered from a communication's perspective. There are already in the market several forecasting tools and will be many more in the future because of increased interest (e.g. for predicting the level of the power consumption in order to be more active in the power market).

2.3.4 ICT 5G requirements for Power Quality Evaluation service

Number of endpoints

See State Estimation service for the number of endpoints where measurements that will be used for Power Quality Evaluation service can be present.

Accordingly, most of the communication will be in the uplink direction, analogue data from sensors to APMUs, and digital from APMUs to the SOGNO Database, and the ViSA.

Latency

The overall latency is in general not a critical issue for this service. Similar requirements to those applied for the SE service can be considered.

Sampling rate

Differently from State Estimation service; for the monitoring of certain power quality parameters, a high reporting rate can be needed. Commercial PMUs or Power Quality analyzers support power quality and can have up to 50 messages per second.

Message volume

See State Estimation service, since the same measurement device can be used also for Power Quality Evaluation service measurements collection.

The overall amount of data per second for a typical LV feeder is low: the expected average data volume for a typical output of each APMU will be no more than 0.5 MB per day. However, this will depend on each specific requirements of the DSO for monitoring frequency and algorithms.

Bandwidth (per device)

Maximal required bandwidth per device depends on the used protocol. If MQTT is used containing the headers (56 B fix) and payload with maximum 30 measurement values and the time stamp (20 B per value + 20 B for timestamp), the message size would be 676 B.

With the maximal sampling rate of 50 messages per second, the bandwidth would be 33.8 KByte/s = 270.4 Kbps

Reliability

Reliability is important but not critical. Even if there are missing data, the operation of the power grid will not be severely affected.

Availability

99.99% (4 nines meaning communications downtime per month of 4 minutes) is recommended.

Security

Security is important not for running the service itself but for the importance of the information and data collected from the DSO.

Table 2.4 shows ICT 5G requirements for the Power Quality Evaluation service.

Table 2.4 ICT 5G requirements for Power Quality Evaluation service

ICT 5G requirements	Power Quality Evaluation service
Req-PQE-endPoints	Few 10’s per km^2 in urban areas
Req-PQE-latency	Not critical
Req-PQE-sampleRate	Up to 50 measurements per second
Req-PQE-volume	676 B per message
Req-PQE-bandwidth	270.4 Kbps
Req-PQE-reliability	Important but not critical
Req-PQE-availability	99.99% (communications downtime per month of 4 minutes)
Req-PQE-security	Important

2.3.4.1 Timescales and preconditions relevant to the commercial scale use of Power Quality Evaluation service

Power Quality Evaluation service is monitoring some power grid quality parameters in more details. Accordingly, the same reasoning described for State Estimation service applies to Power Quality Evaluation service,

2.3.5 ICT 5G requirements for Power Control service

Number of endpoints

Number of devices can be very high, also hundreds of end points per km^2 in areas with high penetration of renewable sources. Communication is bi-directional from generation to control center and vice versa.

Latency

For the communication from generation to control center, the rate of collection of the data can be up to 1 second for steady state control. If dynamic control is done, higher reporting rates could be needed (but this is not done in SOGNO).

The communication from control center to the generation units, when it is needed, can be done every second in the case of steady state control. In these cases, it is not critical but still very important to have low latencies in order to take immediate countermeasures to solve possible problems in the grid. Also, we developed different versions of the power control algorithm where the generation units talk to each other and need to communicate some control parameters one another. In this case, short latencies are even more important. Accordingly, low latency is almost critical.

Sampling rate

In the future we can expect devices sending up to 1 message per second.

Message volume

Voltage and power measurements are sent from the generation unit to the control center; set points are sent from the control center to the generation units. The communication from generation to control has to be periodic, for example every second. The communication from the control to the generation units occurs only when there are problems in the grid. In these cases, the communication can be of a pair of set points every second. However, it is worth noting that different implementations of the power control algorithm can be used, which work differently and can require the communication of some control parameters among the different generation units with higher reporting rate.

Bandwidth (per device)

Maximal required bandwidth per device depends on the used protocol. If MQTT is used containing the headers (56 B fix) and payload with 2 values (either measurements or pair of set points) and the time stamp (20 B per value + 20 B for timestamp), the message size would be 116 B (downlink message).

With the maximal sampling rate of 1 message per second, the bandwidth would be 116 Byte/s = 928 bps = 0.928 Kbps

Reliability

Reliability is very important. The command actions are essential to keep the grid within the expected operation limits, so, the sent commands need to reach the receiver. Lack of communication will not create a blackout, but it can affect the performance and operation of the grid.

Availability

99.99% (4 nines meaning communications downtime per month of 4 minutes) is recommended.

Security

Critical. This is an important service to avoid operational issues in the grid and solve them when they appear. DSO cannot allow interferences in this communication.

Table 2.5 shows ICT 5G requirements for the Power Control service.

Table 2.5 ICT 5G requirements for Power Control service

ICT 5G requirements	Power Control service
Req-PC-endPoints	Up to 100's per km^2 in areas with high penetration of renewable sources
Req-PC-latency	10's ms
Req-PC-sampleRate	1 message per second
Req-PC-volume	116 B per message
Req-PC-bandwidth	0.9 Kbps
Req-PC-reliability	Critical
Req-PC-availability	99.99% (communications downtime per month of 4 minutes)
Req-PC-security	Critical

2.3.5.1 Timescales and preconditions relevant to the commercial scale use of Power Control service

Nowadays completely local control actions are implemented according to distribution grid codes in order to tackle possible problems associated to the high penetration of renewable sources. If regulations change quickly and DSOs are allowed to invest in software, the usage of Power Control service can be expected to increase in a large degree. Power control algorithms will be deployed firstly in those parts of the power grid where the issues caused by high penetration of RESs are faced. The same effect of increase of usage of voltage control services is foreseen.

2.3.6 Summary of ICT 5G requirements for SOGNO services

This section summaries the ICT 5G requirements relevant for SOGNO services elaborated in this document.

The following Table 2.6 shows ICT 5G requirements the most relevant for SOGNO services.

Table 2.6 Summary of ICT 5G requirements for SOGNO services

Energy Scenarios / ICT Requirements	SE	FLISR	LGP	PQE	PC
Endpoints [km^2]	10's	<5	10's	10's	100's

Latency [ms]	1000	<10	Not critical	Not critical	10's
Sampling Rate [meas. per sec]	1	NA	0.01	50	1
Message Volume [kB]	<1	<1	<1	<1	<1
Bandwidth [Kbps]	5.4	NA	0.09	270.4	0.9
Reliability	Important	Critical	Important	Important	Critical
Availability	99.99%	99.999%	99.9%	99.99%	99.99%
Security	Critical	Critical	Important	Important	Critical

2.4 Potential ICT 5G solutions for SOGNO services

This section describes potential 5G solutions for SOGNO services. The following SOGNO services were considered: State Estimation (SE), Fault Location Isolation and Service Restoration (FLISR), Load and Generation Prediction (LGP), Power Quality Evaluation (PQE) and Power Control (PC).

Relationship between the ICT 5G solutions and SOGNO services is indicated in Table 2.7.

Table 2.7 Relationship between 5G ICT solutions and SOGNO services

SOGNO service / ICT 5G Solution	SE	FLISR	LGP	PQE	PC
Providing communications links to new endpoints in the energy system	x	x	x	x	x
Use of non-public 4G (LTE) or 5G networks	x	x	x	x	x
Mobile networks for massive IoT communications	x	x	x	x	x
Ensuring End-To-End latency of 10 to 20 ms		x			x
Using Distributed Edge Computing features to reduce the latency requirements and provide local hosting of algorithms	x	x		x	x
Network Slicing for energy provider control of QoS and security features	x	x		x	x
Use of public 5G networks without network slicing and public 4G (LTE) networks			x		
Use of communications friendly protocols to maximise the reliability of the communications	x	x	x	x	x

In further text, ICT 5G solutions listed in Table 2.7 are described in detail.

Providing communications links to new endpoints in the energy system

Wireless communications systems, such as 5G, will offer cost-effective and easy to deploy solutions to supply communications over shorter distances to connect individual new assets which are part of the distribution grid management scenario to fixed networks. In a mobile wireless network, it is normal to have a fibre optic cable connecting each base station and antenna to the backbone of the 5G and general communications transmission system. This means that only the distance between the sending device (communications module or gateway) at the new asset (e.g., a wind turbine) and the nearest 5G base station antenna is actually communications over the air. Once the signal reaches the base station, it is transmitted further within the 5G and other communications networks to the intended receiver over fixed communications links.

Use of non-public (private) 4G (LTE) or 5G networks

A non-public (sometimes also called private) mobile network could be deployed by a DSO or Transmission System Operator (TSO) to provide part or all of the communications links required to use the scenarios defined above. Non-public networks offer the advantage that the owner has complete control of the priorities, security, configuration and access to the network. Public networks can be used to completement the use of no-public wireless networks, for example, enabling single remote locations to be reached by public networks.

Mobile networks for massive IoT communications

When communication latency is not critical requirement, besides 5G, other network technologies for massive IoT type communications can be utilised like EC-GSM-IoT, LTE-M and NB-IoT. 4G (LTE) and 3G mobile networks can also be considered if the requirements can be fulfilled in such cases.

If components requiring communications are in very deep basements (more than 2-3 levels below ground, or in rooms with particularly heavy concrete walls, the penetration of the 4G (LTE) or NB-IoT communications devices may require the deployment of small repeaters, with cabled connections, to ensure reliable communications.

5G networks will also provide excellent communications solutions for such scenarios. Repeaters for the indoor use of 5G spectrum will be introduced to the market in coming years ensuring that 5G will operate in deep basements and in buildings hosting critical infrastructures with reinforced walls.

Ensuring End-To-End latency of 10 to 20 ms

To achieve end-to-end latencies under or equal to 10 ms 5G wireless links or fixed cabled connections are very likely to be required as a solution.

Latencies of down to 20 ms can be achieved by 4th Generation (LTE) wireless networks. The configuration of the network in the exact locations would have to be investigated to check that the network in question could provide these latencies for each individual link.

Using distributed edge computing capabilities to reduce the latency requirements and provide local hosting of algorithms

In order to reduce the requirements on latency over the wireless link, so that a 4G (LTE) or slower wireless link could be used, and also potentially, to enable hosting of the power system algorithm close to the assets, edge computing capabilities enabled by 5G could be included in the architecture of appropriate communications solutions.

Network Slicing for energy provider control of QoS, reliability and security features

If the energy provider wants to ensure the quality of service, maximum reliability and the security of the communications on an end to end basis, they could use Network Slicing features of 5G networks to set their own priorities for communications resources reserved for their slice and to use whatever communications security mechanisms they consider appropriate. The 5G networks used could be privately owned by energy providers or could be public 5G networks, or any combination of the two.

Use of public 5G networks without network slicing and public 4G (LTE) networks

In a public 4G/5G network, the bandwidth available is shared between many users without reservation of network resources resulting in the situation that if there is very heavy traffic load on the network, it is possible that network congestion may result in reduced reliability and increased latency of the communications. Complete loss of individual packets is possible in such rare circumstances.

Use of communications friendly protocols to maximise the reliability of the communications

The packets to be transmitted are of small size, of the order of magnitude of several hundred kilobits of information. The protocols used by the energy systems should preferably be chosen so that they optimise the efficiency of the use of the wireless communications channel. Examples of commonly used energy protocols which make efficient use of wireless communications channels include Message Queuing Telemetry Transport (MQTT) and Advanced Message Queuing Protocol (AMQP) and other Transport Control Protocol (TCP) based protocols. The use of the 61850 Sampled Value protocol is not the most appropriate for certain power system applications as this protocol does not confirm the arrival of packets. Other energy protocols, such as 61850 Generic Object-Oriented Substation Events (GOOSE) can generate communications problems as it produces bursts of traffic which can suddenly overload wireless channels and cause delays in transmission.

2.5 Conclusions on the ICT latency requirements of the SOGNO services

The SOGNO field trials provided the project partners with a clear set of requirements on the latency of communication which had to be achieved in order to operate the SOGNO services in the field in the next future. These requirements were used as a baseline for evaluating the performance of 4G and 5G networks in the tests reported later in Chapter 5 of this document.

These requirements will constantly evolve to become more challenging as power network providers increasingly require more accurate and frequent updates from measurement equipment to enable them to optimally manage the power network assets. In this context, the investigation of how to optimize 5G radio network latencies and our recommendations on how latency can be optimized, reported in the following chapters, provides insights into improving the latency performance which 5G.

Implementation of our recommendations in public and non-public 5G networks used to support utility services will decrease the latency of the communications and improve the ability of 5G to support the most challenging latency requirements of evolving and future power network services. An optimized 5G network will enable power service developers to further enhance their services to take advantage of the reduced latency and provides near real-time visibility and control of power networks to power network operators.

3. Generating data streams typical of SOGNO services for use in laboratory tests

For the laboratory tests, the SOGNO services were not deployed in a live power grid environment. Instead, a synthetic data stream was generated in order to simulate the messages of the SOGNO services. The data stream was then transmitted over a mobile radio network and the latencies of each message of the data stream were measured.

This chapter explains how the data for the laboratory tests were generated and what the characteristic traffic patterns of the data streams are.

3.1 Generating the data streams

In the tests, the simulated traffic of the services was generated by a power grid simulator or a synthetic data generator. For the radio network, it is irrelevant how the traffic is generated because eventually, both streams were identical.

3.1.1 Power grid simulator

The power grid simulator is used to emulate a live power grid scenario. With the simulation of power grids, information regarding the current and voltage between the power grid's components is gathered and sent to the State Estimation service. The State Estimation service evaluates that information and determines the state of the power grid and its electrical quantities. The data transmission between the simulator and the State Estimation service is performed using the MQTT protocol. Therefore, the data is published from the power grid simulator to the MQTT Broker in the first step. Then, State Estimation service receives the data subscribing to the MQTT Broker.

The power grid simulator, State Estimation service and MQTT broker are deployed on the Docker platform. Hence, they can run in compatibility.

3.1.2 Synthetic data generator

In order to be more flexible in terms of modifying the traffic patterns of a data stream, a synthetic data generator was created using the Paho Python library [1]. This generator took a single recorded message as input instead of creating MQTT messages from scratch as the Power Grid Simulator did. A data stream of MQTT messages according to the requested traffic pattern was generated sending the same recorded message serially with a specific MQTT topic. With the synthetic data generator, the MQTT broker was installed on the network side. Depending on the communication direction (uplink or downlink), the MQTT publisher and subscriber clients were deployed on opposite sides. The receiver side subscribed to a specific MQTT topic by connecting to the MQTT broker. The sender side published messages to the MQTT broker.

3.2 Traffic patterns of the data streams

The traffic patterns of the SOGNO services were specified in terms of **message size** and **message frequency**. The frequency was adjusted by generating and sending the messages in equal intervals. The duration of the intervals, in the following, is referred to as **message period**.

In some test cases, a shorter message period than the specified requirement was used, in order to investigate the possibilities of the radio link to handle higher message frequency. That might become relevant for future power scenarios. With the 5G end-user device available at present for testing, the maximum frequency of messages per second which could be usefully used in tests was 5 messages per second in the downlink and 10 messages per second in the uplink. The minimum message period of 200 ms in the downlink and 100 ms in the uplink resulted. In future tests, other 5G-end-user devices could be used to be able to also test higher message frequencies.

The five SOGNO services were categorized into **unidirectional** and **bidirectional** services. Unidirectional services only transmit information from the grid to the central station, for example to send monitoring data. State Estimation, Load and Generation Prediction and Power Quality Evaluation are SOGNO services with unidirectional characteristic. On the other hand, bidirectional services require a data link in both ways, because control commands need to be sent to the grid as well. FLISR and Power Control services are categorized as bidirectional services.

3.2.1 Communication characteristics of the unidirectional service

Unidirectional services send information about the grid operating conditions, which the measurement devices recorded, to the control station. The traffic for the tests with unidirectional services was generated by the power grid simulator. The messages had the same structure and data format defined for the field implementation of the State Estimation service, even if in this case simulated values have been used.

A range of message frequencies were used in the test cases because each SOGNO service generates messages with different message frequencies and we aimed to investigate the 5G radio network optimization for a selection of these message frequencies. A message frequency of 50 messages per second, which is supported by the Power Quality Evaluation service, could not be tested, because of the 5G end-user device’s limitations. Information sent by unidirectional services is only delivered in the uplink direction, from the power grid simulator to the radio network. Hence, downlink traffic is not evaluated in the tests of unidirectional services.

3.2.2 Communication characteristics of the bidirectional service

Bidirectional services send information in both directions between the measurement device and the control station. The messages were produced by the synthetic data generator and they had the characteristics of the FLISR service. Since the FLISR service only transmits messages when there is a fault detected in the grid, it was not feasible to simulate realistic traffic in terms of the message frequency. Instead, 5 messages per second were generated and transmitted. This message frequency is the maximum that the available 5G end-device could handle.

3.2.3 Categorizing the services and their communication requirements

The following Table 3.1 categorizes the five SOGNO services in terms of their communication direction. Additionally, their latency requirements, as currently defined for the use of the services in field trials, are stated.

Table 3.1 Overview of the SOGNO services and their characteristics

SOGNO Service	Communication direction	Message frequency requirement [messages per second]	Latency requirement
State Estimation	Unidirectional	1	1000 ms
Load and Generation Prediction	Unidirectional	0.01	Not critical
Power Quality Evaluation	Unidirectional	50	Not critical
Fault Localization, Identification and Service Recovery (FLISR)	Bidirectional	N/A	<10 ms
Power Control	Bidirectional	1	20-30 ms

4. Laboratory infrastructure for 4G and 5G radio network optimization tests

Ericsson provided a laboratory infrastructure for testing of the performance of 4G and 5G networks in transmitting streams of messages produced by the SOGNO services. The infrastructure included non-public 4G and 5G networks running with live over the air transmission in the laboratory. The over the air transmission was at very low power and used test frequencies rather than the frequencies used by public mobile networks.

This test infrastructure is typical of the type of mobile network equipment that would be used to provide 4G and 5G services for power network operators. Such network equipment could be owned and operated by public mobile network operators (e.g. Vodafone or T-Mobile). Increasingly, power network operators are purchasing and operating their own non-public mobile network infrastructure to support the operation of their power networks. In many cases, a hybrid mobile communications infrastructure consisting of a combination of public and non-public mobile networks is likely to be used to support power network operations.

A brief overview of the configuration and of the components of the test infrastructure is provided in the sub-sections below.

The data streams of the SOGNO services were generated within the infrastructure and they simulate the data streams observed in field trials of live power networks as explained in Chapter 3 above. The transmission of the data streams over the air in the 4G and 5G infrastructure was measured to determine the latency with which messages were received.

4.1 An Introduction to mobile communications networks

A mobile operator network is shown in Figure 4.1.

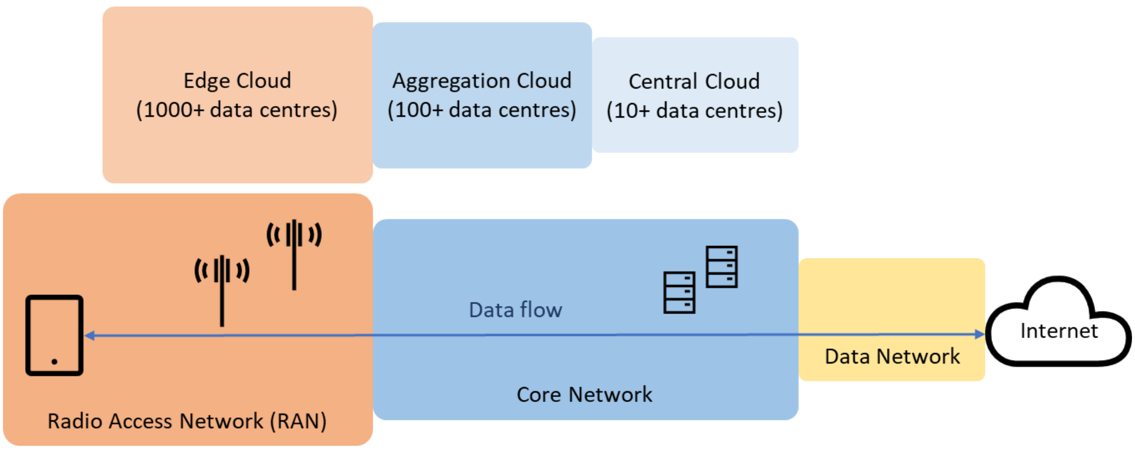

Figure 4.1 Mobile operator network

A mobile network consists of two key parts – the **radio access network**, which provides the transmission of signals over the air to sensors, modems and devices such as mobile phone, and the **Mobile Core network** which provides the management functions needed to operate the network as a whole. A radio access network cannot work without being connected and supported by a mobile core network.

The core network aggregates data traffic from end devices, such as sensors, modems attached to measurement equipment, etc. The core network authenticates subscribers and devices, applies personalized policies and manages the mobility of the devices before routing the traffic to data networks, operator services or the Internet.

The Data Network is the network that routes the data to the internet or hosts the content data servers or enterprise servers.

The SOGNO partner EDD was able to provide both **Ericsson 4G and 5G radio and core networks**, located in the Ericsson offices in Herzogenrath, Germany for use in tests. The Ericsson network systems were complemented by the use of a **5G OPPO Phone** [2] and a **4G Quanta Dongle** which were used to interface the SOGNO service data streams to the mobile network. Ericsson does not manufacture such end user devices.

In the set of tests reported in this deliverable, the focus was on **optimizing the parameters** which can be adjusted in the **Radio Access network**, to reduce the latency of transmission over the air to a minimum offering the best possible support to the SOGNO services.

4.2 The mobile network configurations implemented for the SOGNO radio network optimization tests

A schematic diagram of the laboratory infrastructure is illustrated in Figure 4.2. On the left, the green box represents a PC, where the data streams for the laboratory tests of the SOGNO services are generated or received. Attached to the PC is a radio modem, a 4G dongle or a 5G phone, depending on the radio network. The modem transmits the data streams over the air. The data streams are generated by the PC to the network and receives data streams generated by the mobile network. The over the air communication between the antennas of the radio modem and the mobile network is illustrated as a blue dotted arrow. On the right, the green box symbolizes the mobile 4G or 5G network. For our tests, the SOGNO services are hosted in the non-public mobile network, in a cloud instead of in a power network operator's central server or remote cloud. The network also includes a Network Time Protocol (NTP [3]) server, which is used for time synchronization. The cable link using Ethernet, illustrated as a dotted line, from the NTP server to the PC is only needed for precise latency measurements in the laboratory infrastructure and it will not be part of field trials in a real power network.

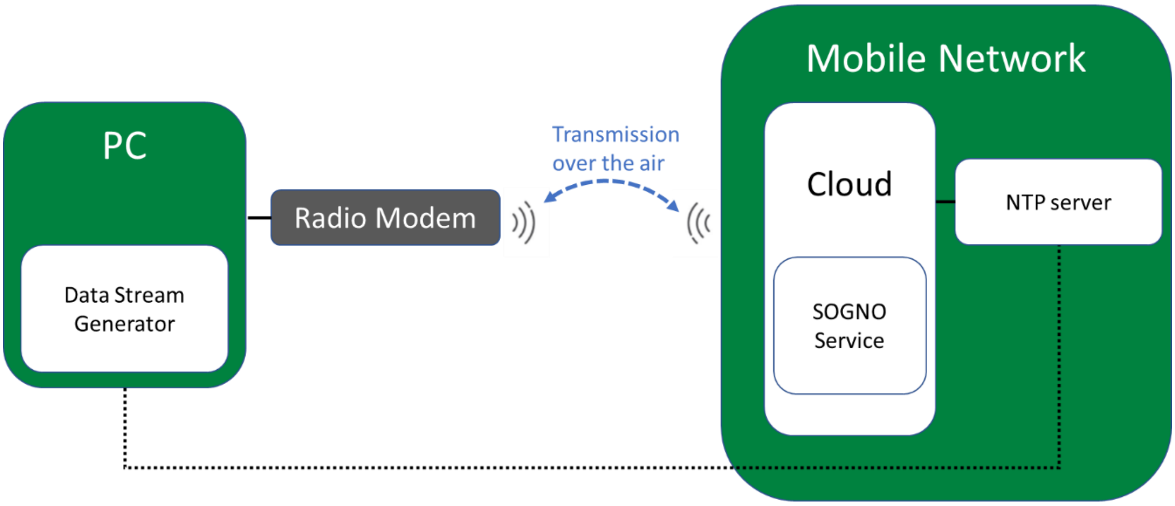

Figure 4.2 Schematic diagram of the laboratory infrastructure

4.3 Hardware components of the laboratory test infrastructure

The laboratory test infrastructure contains of single hardware components (see Figure 4.3), which were linked together such that they form the system illustrated in Figure 4.2.

In the following sections, each of these components will be described in detail.

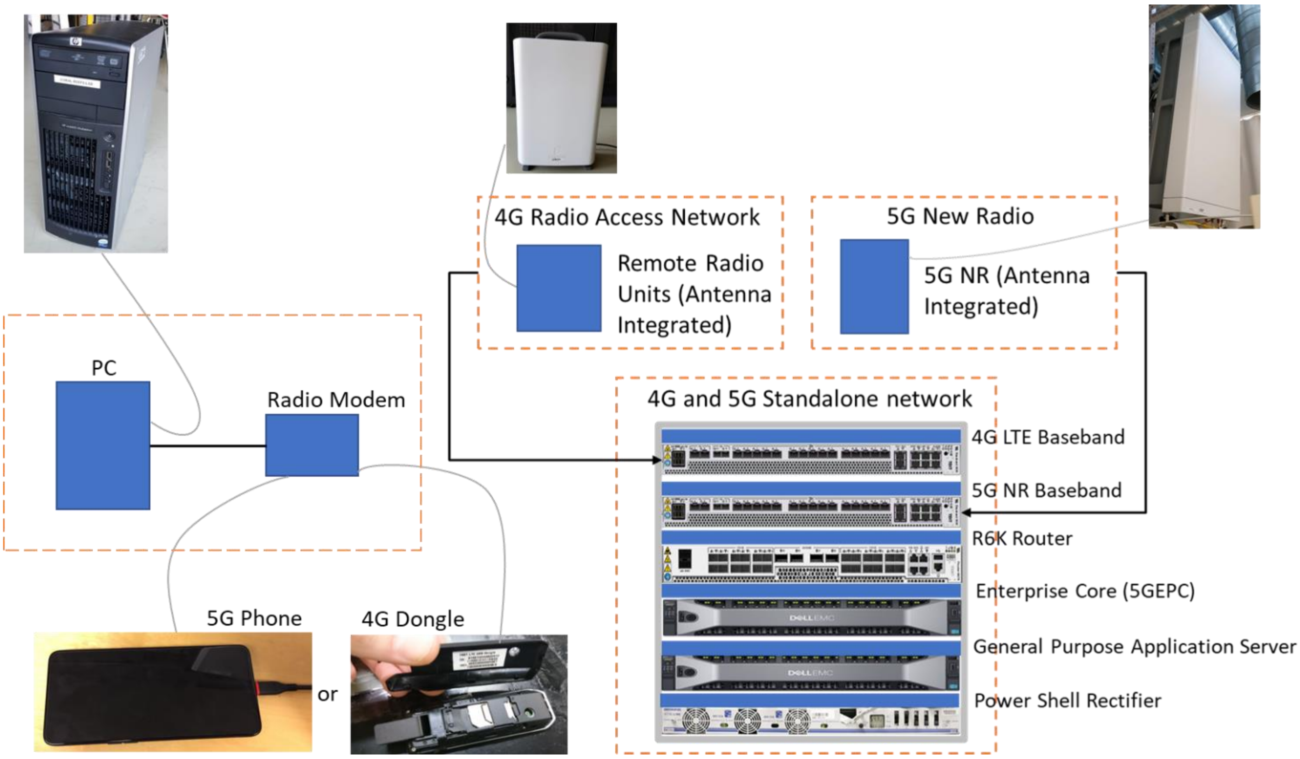

Figure 4.3 Overview of the hardware components of the laboratory test infrastructure

4.3.1 PC

A Linux PC, running on Ubuntu 18.04, was used in the laboratory test infrastructure. It was placed close to the radio network, so that the attached radio device was able to establish a connection to the network. In the tests of unidirectional services, the data streams were generated here. In the tests of downlink for bidirectional services, the data streams were received here.

4.3.2 Non-public 5G network

The non-public 5G network consisted of an antenna and Remote Radio Unit (RRU), Baseband Unit (BBU), R6K router and two Dell servers. The network was located at EDD in Herzogenrath. At the time of the tests, the 5G-URLLC (Ultra Reliable and Low Latency Communications) features were not released yet. The latency values using that profile are expected to be lower than the latency results obtained in the set of tests described in this document.

4.3.3 Non-public 4G (LTE) network

The 4G (LTE) Network consisted of an antenna and the micro Radio Resource Unit, the Evolved Node B (eNB), the Baseband Unit and the core network, which was running on the same hardware as 5G. The 4G and 5G core network used the same software release 19.3. The network was located at EDD in Herzogenrath, Germany.

4.3.4 Cloud

The cloud platform was installed on the enterprise core network. The core network was virtualized and running on the cloud platform. The user applications of energy services were deployed in the cloud.

4.3.5 5G phone

For the connection to the 5G network, a mobile phone by OPPO, model Reno 5G, was used. It runs on an Android-based operating system, ColorOS V6.0.

4.3.6 4G dongle

For the connection to the 4G (LTE) network, a 4G-dongle by Quanta Computer Inc., model: 4070 was used. It had a SIM card inside and was configured with the Mobile Genie software.

4.4 The radio network infrastructure used in the SOGNO tests

As described in Section 4.1 above, the focus of and tests reported in this document, was on the optimization of the parameters of the 5G radio network to enable it to support the SOGNO services with the lowest achievable communication latency. Potential optimizations of the Core Network functionality were not addressed in this study.

In this sub-section, we describe the features of the 4G and 5G radio networks which were used for the tests, the parameters of the networks which we modified and tested to define optimizations to latency for each SOGNO service, the techniques we applied to measure latency in our test infrastructure and how we provided time synchronization in the infrastructure.

The following Table 4.1 shows the properties of the radio networks (see Section 4.1.1 and 4.1.2) which were available for the tests reported in this deliverable.

Table 4.1 Radio access test system specifications

Radio Access Specifications	4G (LTE)	5G
Radio frequency spectrum band	B7	n77
Bandwidth	5 MHz	100 MHz
Transmission power	10 mW	400 mW
# of RX antennas	2	N/A
# of TX antennas	2	N/A
DL frequency band	2622.5 +/- 2.5 MHz	3670.02 +/- 50 MHz
UL frequency band	2502.5 +/- 2.5 MHz	3670.02 +/- 50 MHz
Modulation	DL: 64QAM[1)], UL: 16QAM	DL: 256QAM, UL: 64QAM
Technology	FDD [2)]	TDD[3)]

Note 1): Quadrature amplitude modulation

Note 2): Frequency Division Duplex

Note 3): Time Division Duplex

4.4.1 Radio parameters optimized in our 5G test series

In order to get better performance of the SOGNO services used in 5G networks, radio parameters were adjusted to achieve the optimal radio network performance. The most important radio parameters related to latency, which could be adjusted in the systems available for this set of tests, are:

- The Prescheduling Data Size,
- The maximum number of Hybrid automatic repeat request (HARQ) transmissions,
- The choice of Modulation and Coding Scheme (MCS) used, and
- The number of Physical Resource Blocks (PRB) available.

Prescheduling is a function used in the uplink direction. The network can preschedule and reserve resources to reduce waiting time until data can be sent. Prescheduling Data Size specifies how many bytes are allocated to a prescheduling period.

HARQ is a protocol implemented in the MAC layer. It ensures, that a packet will be retransmitted if it is not acknowledged. The main advantage of using HARQ transmissions is that if any acknowledgement packet is not received by sender, the packet is retransmitted from the MAC layer not from the upper layers. Hence, less resources are used, and latency occurred due to retransmission is less than any upper layer retransmissions.

As another parameter **MCS** was changed. Depending on different MCS values, the base station determines which modulation order (QPSK[1], 16-QAM, 64-QAM) is used to transmit data in the network. The choice of MCS depends on the channel quality and is usually adjusted to changing conditions.

With the **PRB** parameter, the resources reserved in the network were arranged on the physical layer. The maximum number of PRBs that is allowed to use was limited by modifying this parameter.

The performance of the 5G radio network was tested for the SOGNO services under various settings of the four parameters described above and the optimal settings were identified using the test results.

4.4.2 Measuring latency in the test infrastructure radio networks

In order to measure the latency of the transmitted messages, the network traffic was traced with the Linux tool ‘tcpdump’. The measuring point at the PC is the interface to the radio modem. On the network side, the traffic is traced in the cloud. The resulting timestamps of the sent and received message were then extracted. In order to compute the latency, the times of the received and the sent message were subtracted.

4.4.3 How time synchronization was implemented

Since the difference between timestamps was used to measure latency, it was important to synchronize the clocks of all the entities relevant to the tests. Our tests used timestamps from two separate entities (a PC and a cloud), which were running on two different clocks, so they needed to be synchronized. They were synchronized using Network Time Protocol (NTP). NTP is an Internet Protocol that is used for clock synchronization.

A gateway in the core network was used as an NTP server. Since the gateway was in the network, the cloud was able to directly get the clock information from the gateway. In order that the PC could get the clock information from the same gateway, the PC was connected to the network using an ethernet cable. Using this configuration, the offset for the clock information on the PC side was minimized.

To verify if the synchronization was working precisely, a test with Ping messages was performed between the PC and the cloud. For that test, 2000 Ping requests were sent with 1 second intervals from the PC to the cloud. By tracing the messages on both ends, the latency of the Ping requests was measured. Moreover, the latency of the Ping responses, which were sent from the cloud to

[1] Quadrature Phase-Shift Keying

the PC was measured. The latencies of the corresponding requests and replies was summed and then compared with the Ping Round-Trip Time (RTT) values.

The average difference between sum of one-way latencies and the RTTs was 0.02996 ms. The standard deviation was 0.01777 ms. This result showed that NTP synchronization was precise enough for the purposes of our series of tests.

4.5 Limitations of the radio network test infrastructure

Many issues affecting the performance of large scale commercial 5G-based ICT infrastructure in the field could not be reproduced in the laboratory test environment available for the SOGNO tests.

The 5G-based ICT test infrastructure used for the SOGNO tests reported in this document differs from a commercial 5G-based ICT infrastructure in the field with respect to the following issues:

- **No handover** between base stations was possible in the laboratory and the devices used were stationary. The devices had a fixed distance relationship to the base station in the laboratory. In a full-scale 5G 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 performance characteristics** of the equipment and deployed software used in the laboratory can differ from the hardware and software used in a full-scale live infrastructure. E.g., processor, memory and discs performance, software versions, etc of systems used in the field will often be optimised compared to the performance of laboratory prototype equipment, such as that used for these tests.
- There will be **less interference** on the radio interface in the test lab and the devices have optical visibility to the antenna. In a real deployment, there will be obstacles in the environment causing many reflected signals, each with a different time delay and phase when they arrive at the receiver.
- In a test environment, a **limited number of traffic types** can be utilised compared to the full range of traffic types in a real-world application.
- **Packet loss** in a real environment is higher than that in a test lab.

Despite these limitations and differences, the results obtained in our laboratory tests are representative of the results which can be achieved in large scale commercial infrastructure using the optimizations tested and reported in this document.

The relationship between power network service simulations and large scale deployment of the same power network services is the field is described in deliverable D5.3.

4.6 Limitations of devices and systems used in the laboratory tests

In the laboratory test infrastructure, the latest available equipment available was used. During the tests, the following limitations regarding the infrastructure and its components were still encountered:

- 5G device
- VPN tunnel
- Simulated data streams

One limiting factor was the **5G OPPO phone**. It could not handle a burst of messages from multiple data streams or high message frequencies. That is the reason why the message period in the test cases is not set below 100 ms. The SOGNO Power Quality Evaluation service can generate messages with a message period of up to 20 ms (50 message per second to be transmitted) in the field. However, the 5G OPPO phone device could not support such a high frequency of message transmission. Hence, this service could therefore not be evaluated to the most detailed level using this equipment. Tests with all other services could be run as in a field trial in a live power network.

Another limitation of the phone was **the need to use a VPN tunnel**. Since the OPPO phone is a commercial product, it could not be configured in a way that it forwarded the incoming messages to the PC. Therefore, a VPN tunnel was built between the PC and the 5G network, so that the cloud could reach the PC via the phone. Using a VPN tunnel in the 5G setup caused additional traffic to the actual data of the service. That lowered the performance of the radio link and latency was slightly increased.

The transmitted and measured **data stream** traffic was not associated to real data. Instead, simulators were used to generate the data streams. The traffic for unidirectional services was produced by the power grid simulator provided by RWTH and the traffic for bidirectional services by the synthetic data generator. However, from a communication perspective, it is irrelevant how the data is generated. The results of the tests can be treated as if the data stream was measured in a real power grid scenario, even because the same data structure and format as in the field-deployed services have been used.

4.7 Conclusion of test infrastructure establishment

The test infrastructure was configured to enable the testing of 5G optimisations in relation to their effect on the latency of SOGNO service data stream. It provided a state-of-the-art testbed for the series of tests. The limitations of the test infrastructure were the normal limitations encountered in laboratory testing of mobile networks. The test infrastructure was able to provide a representative environment for measurement and optimisation of 5G radio network latency.

5. Test cases and results of the 5G optimization study

This section describes the series of tests undertaken for unidirectional SOGNO services as well as the test series for bidirectional SOGNO services.

The objective of the test series focused on optimizing the radio parameters, presented in Section 4.3. During the test series, the laboratory test infrastructure described in Section 4 was used to transmit and optimize the latency of the data streams, presented in Section 3.2.

The latency results of the tests are presented with the **average** (arithmetic mean). To show the improvements of the optimizations, we have chosen to focus on the 90th percentile, which represents 90% of the messages. This is the range, where the optimization had the biggest effect and the **maximum latency reduction** could be seen.

5.1 Performance tests of unidirectional services

A set of test cases was developed for this study in order to test different optimizations of the performance of 5G for the unidirectional services. Since data of unidirectional SOGNO services is only transmitted in the uplink, only this communication direction is measured in this chapter. The first test case (1.1 below) compared the performance of 4G and 5G networks. In the following test cases (1.2 to 1.5 below), the performance of the 5G network was optimized by changing a range of radio parameters. Prescheduling data size, MCS, HARQ and PRB were individually changed in separate test cases. The same sequence of steps was executed for each test case.

5.1.1 Steps of the test execution

An overview of the sequence of actions used to conduct the tests is provided here. This sequence was executed for all test cases described in Section 5.1.

- The tcpdump was started on the PC interface to record origin time stamps,
- The tcpdump was started on the 5G cloud to record destination time stamps,
- The potential radio parameters were set on the baseband unit,
- The message subscriber was started on the 5G cloud,
- The power grid simulator and the MQTT broker were started on the PC,
- The MQTT messages were sent,
- The tcpdump was stopped on the PC and the cloud,
- The trace files for each test sequence were collected, and finally the
- Latencies for each test sequence were computed.

5.1.2 Test case 1.1: comparison between 4G and 5G uplink latency for unidirectional service

Test Case 1.1
Measurement of uplink latency of communication channels between the device and the 5G cloud hosting SOGNO unidirectional service in 4G and 5G network

5.1.2.1 Test condition

The setup consisted of a 4G and 5G network and power grid simulator generating MQTT messages for State Estimation service. The 4G network had the latest release with the best available performance. Prescheduling was enabled in both networks. The MQTT messages were sent every 1 second for 5 minutes. The message size was 780 B.

5.1.2.2 Result and conclusion of this set of tests of uplink latency for unidirectional services comparing 4G and 5G radio

A significant latency reduction between 4G and 5G network was observed in the uplink communication direction. The average uplink latency was decreased from 29.73 ms using the 4G (LTE) network to 4.66 ms using the 5G network. In the 90th percentile, latency was reduced by 85.7% when the newer 5G radio technology was used.

Decreasing the latency by using 5G is not mandatory for the basic SOGNO State Estimation service to run flawlessly. The latency requirement on the SOGNO State Estimation service is 1 s and can be met even with 4G (LTE).

However, lower latencies of the radio link can enable more complex implementations of the State Estimation service, for instance coordinating the processing algorithms in different locations. Lower latencies, which can be achieved by using 5G, could be beneficial for faster reactions and visualization of the results.

Average 4G uplink latency	Average 5G uplink latency	Maximum latency reduction
29.73 ms	4.66 ms	85.7%

5.1.3 Test case 1.2: 5G uplink latency for unidirectional service optimizing prescheduling data size radio parameter

Test Case 1.2
Measurement of uplink latency of communication channels between the device and the 5G cloud hosting SOGNO unidirectional service in 5G using a range of uplink prescheduling data sizes

5.1.3.1 Test condition

The setup consisted of a 5G network and power grid simulator generating MQTT messages for State Estimation service. A range of prescheduling data sizes was used. The MQTT messages were sent every 1 second for 5 minutes for each test series. The message size was 780 B.

5.1.3.2 Result and conclusion of this set of tests of uplink latency for unidirectional services optimizing prescheduling data size radio parameter

This test case showed that by carefully adjusting the prescheduling data size parameter, the performance of the service was significantly improved. When the prescheduling data size was increased to be larger than 780 B, the latency could be reduced by 45.5% compared to the latency observed for smaller prescheduling data size parameter settings. Using the optimized parameter settings, the test case provided an average 5G uplink latency of 4.87 ms. That result is related to the fact that a message with a size of 780 B or more fits into one prescheduling period.

The conclusion of this test is that the prescheduling data size should be adjusted to the message size of the service. With that, the uplink latency transmitting unidirectional power services, such as State Estimation, delivers the best performance.

Minimum 5G average uplink latency in this test case	Maximum latency reduction (with respect to non-optimized prescheduling data size)
4.87 ms	45.5%

5.1.4 Test case 1.3: 5G uplink latency for unidirectional service optimizing MCS radio parameter

Test Case 1.3
Measurement of uplink latency of communication channels between the device and 5G cloud hosting SOGNO State Estimation service in 5G with different Modulation and Coding Schemes (MCS) settings

5.1.4.1 Test condition

The setup consisted of a 5G network and power grid simulator generating MQTT messages for State Estimation service. The radio parameter for the maximum allowed modulation and coding scheme was changed. A range of MCS parameters was used. MQTT messages were sent every 100 ms. The number of messages was 10,000.

5.1.4.2 Result and conclusion of this set of tests of uplink latency for unidirectional services optimizing MCS radio parameter

The results of this test series showed that a lower MCS level resulted in a maximum latency reduction of 44% and an average uplink latency of 5.6 ms was achieved. That effect can be explained with the concept behind modulation and coding schemes. A lower MCS requires more radio resources but is more robust to impairments of the channel quality. A higher MCS, on the contrary, is more efficient with resources, but more prone to bad radio conditions. Since Link Adaptation feature was disabled, the MCS was not adapted to changing conditions as it would be done in commercial systems. That can lead to a higher BLER (block error rate), so that more retransmissions are needed to successfully transmit a packet. Eventually, the additional retransmissions are reflected in the increased latency.

In the SOGNO services like State Estimation, reliability is more important than efficient exploitation of the network. Especially, in a scenario with only a small number of measuring devices, the network traffic will not be stressed. Therefore, a low MCS level should be used in order to reduce error rates and be independent of changing radio conditions. Increasing the number of devices significantly, the communication to the central coordinator will be done hierarchically because the State Estimation algorithm will be distributed. In that case, it might be better to adapt the MCS to a medium level to manage the increased network load.

Minimum 5G average uplink latency in this test case	Maximum latency reduction
5.6 ms	44%

5.1.5 Test case 1.4: 5G uplink latency for unidirectional service with optimizing HARQ radio parameter

Test Case 1.4
Measurement of uplink latency of communication channels between the device and 5G cloud hosting SOGNO unidirectional service in 5G with different number of HARQ transmissions

5.1.5.1 Test condition

The setup consisted of a 5G network and power grid simulator generating MQTT messages for State Estimation service. The radio parameter for the maximum allowed number of HARQ transmissions was changed. A range of HARQ parameters was used. MQTT messages were sent every 100 ms. The number of messages was 10,000.

5.1.5.2 Results and conclusion of this set of tests of uplink latency for unidirectional services optimizing HARQ radio parameter

Allowing more transmissions on the HARQ layer improved the latency by 81.25% at most and an average uplink latency of 3.87 ms was obtained. If a transmission on HARQ layer is not successful and the number of allowed transmissions is reached, a higher protocol layer handles the retransmission. Since the higher layer operates on a different schedule, the transmission takes more time and results in higher latencies.

The conclusion of this test case is, that the uplink latency for unidirectional services, like State Estimation, can be optimized by allowing a high number of HARQ transmissions.

Minimum 5G average uplink latency in this test case	Maximum latency reduction
3.87 ms	81.25%

5.1.6 Test case 1.5: 5G uplink latency for unidirectional service optimizing PRB radio parameter

Test Case 1.5
Measurement of uplink latency of communication channels between the device and 5G cloud hosting SOGNO unidirectional service in 5G with different number of PRBs

5.1.6.1 Test condition

The setup consisted of a 5G network and power grid simulator generating MQTT messages for State Estimation service. A range of maximum allowed numbers of PRBs was used. MQTT messages with size of 1, 30 and 1200 values were sent every 100 ms. The number of transmitted messages was 10,000

5.1.6.2 Results and conclusion of this set of tests of uplink latency for unidirectional services optimizing PRB radio parameter

The performance and reliability for the State Estimation service could be optimized when the PRB parameter was set to the maximum. A limited number of PRBs implied, that this radio setting could not manage the network load for large messages because not enough resources were available. Transmitting 1200 values via 5G radio also challenged the network when the maximum number of PRBs were used, but still, the latency requirements were met without exception. In this test case, a minimum average uplink latency in the 5G communication system of 3.95 ms was observed.

The conclusion of this set of tests is a recommendation on the choice of the PRB parameter. The maximum number of PRBs should be allowed to use so that the network is able to cope even with larger message sizes.

Minimum 5G average uplink latency in this test case	Maximum latency reduction
3.95 ms	Latency improvement for a given message size were not observed when the settings for this parameter were changed.

5.1.7 Summary of the conclusions of the test cases for unidirectional services measuring uplink latency

The following Table 5.1 provides a summary of the conclusions of the test cases of Section 5.1.

Table 5.1 Summary of the conclusions of the test cases for unidirectional services

Test Case	Minimum average latency	Maximum latency reduction	Optimal setting
1.1: 4G/5G Comparison	4.66 ms	85.7%	The 5G network supports much lower latency than the 4G (LTE) network.
1.2: Prescheduling data size	4.87 ms	45.5%	The prescheduling data size parameter should be larger than the message size of the service.
1.3: MCS	5.6 ms	44%	A low MCS level provides the highest robustness, while a medium MCS level could be a good compromise between efficiency and performance.
1.4: HARQ	3.87 ms	81.25%	The maximum number of HARQ transmissions should be allowed to get the lowest latency.
1.5: PRB	3.95 ms	Latency improvement for a given message size were not observed when the settings for this parameter were changed.	The maximum number of PRBs should be used to manage high network loads as it provides to optimal radio network performance and enables the optimal support of large message sizes. If message sizes are small, lower numbers of PRBs will provide the same level of performance.

5.2 Performance tests of bidirectional services

The aim of these test cases was to measure the performance of bidirectional services in a 5G radio network. The available radio parameters were tested and optimized to improve the results. The test cases, reported in this sub-section 5.2, measured only the downlink transmission direction. In Section 5.1 above, the uplink direction transmission of unidirectional services was investigated. The knowledge gained in these test cases can also be applied on the uplink transmission direction of bidirectional services. Therefore, a repetition of the same test cases for uplink latency using data streams of bidirectional services was not needed.

Compared to the previous test cases, in which the uplink direction was considered, the downlink showed a better performance with respect to latency and downlink latencies measured were, in general, lower than those measured in uplink tests. This is because, in the downlink direction tests, the base station does not preschedule the transmission as was done in the uplink direction tests. Instead, data could be transmitted as soon as it was available with no delays for prescheduling.

A set of test cases was developed for this report in order to test different optimizations of the performance of the bidirectional services. First, in test case 2.1, we measured the downlink latency of bidirectional services using a range of MCS parameters and in the following test case 2.2, we show how different optimizations of the HARQ parameter improve the basic result. The same sequence of steps was executed for each test case.

5.2.1 Steps of the test execution

An overview of the sequence of actions used to conduct the tests is provided here. This sequence is executed for all test cases under Section 5.2.

- The tcpdump was started on the PC and 5G cloud to record time stamps,
- The potential radio parameters were set on the baseband unit,
- The message subscriber was started on the PC,
- The MQTT broker and the FLISR message publisher were started on 5G cloud,
- The tcpdump was stopped on the PC and 5G cloud,
- The trace files for each test sequence were collected, and finally the
- Latencies for each test sequence were computed.

5.2.2 Test case 2.1: 5G downlink latency for bidirectional service optimizing MCS radio parameter

Test Case 2.1
Measurement of Downlink latency of communication channels between the device and 5G cloud hosting SOGNO bidirectional service in 5G with different Modulation and Coding Scheme (MCS)

5.2.2.1 Test Condition

The setup consisted of a 5G network and synthetic data generator that generated and sent MQTT messages for FLISR service. The messages were sent in the downlink direction, from 5G cloud to the PC. A range of MCS parameters was used. The MQTT messages were sent every 200 ms for 16 minutes. The message size was 206 B.

5.2.2.2 Results and conclusion of this set of tests of downlink latency for bidirectional services optimizing MCS radio parameter

This test case showed, that the choice of the Modulation and Coding Scheme influences the latency. Using a lower MCS level, which is more robust, the latency was reduced by 50% and the average downlink latency was lowered to 3.83 ms. The 5G radio network can achieve this performance because a robust MCS decreases the probability of a transmission failures, so that retransmissions are not needed, and messages are successfully received in the first transmission. The disadvantage of a low MCS level is that the efficiency of the 5G radio bandwidth is reduced because more resources are needed to provide the same performance as that observed for higher MCS levels. In this test case, a low and medium MCS showed similar behavior, so a medium MCS level can be a good compromise to serve the objectives of both robustness and efficiency.

The conclusion of this set of tests is that the use of a lower MCS level produces the best result in the downlink latency of 5G when transmitting the data of bidirectional power services, such as FLISR. However, it should be kept in mind that a higher MCS level enables the transmission of larger volumes of data.

Minimum 5G average downlink latency in this test case	Maximum latency reduction
3.83 ms	50%

5.2.3 Test case 2.2: 5G downlink latency for bidirectional service optimizing HARQ radio parameter

Test Case 2.2

Measurement of Downlink latency of communication channels between the device and 5G cloud hosting SOGNO bidirectional service in 5G with different number of HARQ transmissions

5.2.3.1 Test Condition

The setup consisted of a 5G network and synthetic data generator that generated and sent MQTT messages for FLISR service. The messages were sent in the downlink direction, from 5G cloud to the PC. A range of HARQ and MCS parameters was used. The MQTT messages were sent every 200 ms for 16 minutes. The message size is 206 B.

5.2.3.2 Result and conclusion of this set of tests of downlink latency for bidirectional services optimizing HARQ radio parameter

Using a low MCS level, the HARQ parameter did not show any effect on the latency. In this case, the MCS was robust enough so that HARQ retransmissions were not needed. One HARQ transmission could successfully transmit the message already.

On the contrary, using a high MCS level, it was observed, that retransmissions were needed. When only one HARQ transmission was allowed, the latency increased significantly because higher level retransmissions took more time. The tests with a range of HARQ parameters showed, that allowing a higher number of HARQ transmissions resulted in a maximum latency reduction of 60%.

When retransmissions in the network can occur due to bad radio conditions or the use of a more efficient MCS is required, a higher number of HARQ transmissions should be allowed. This can reduce the average downlink latency to 4.08 ms.

Minimum 5G average downlink latency in this test case	Maximum latency reduction
4.08 ms	60%

5.2.4 Summary of the conclusions of the bidirectional test cases measuring downlink latency

The following Table 5.2 provides a summary of the conclusions of the test cases of Section 5.2.

Table 5.2 Summary of the conclusions of the bidirectional test cases

Test Case	Minimum average latency	Maximum latency reduction	Optimal setting
Prescheduling	Not applicable.		This parameter is not applicable in the downlink, because the network sends the data immediately and scheduling is not needed.
2.1: MCS	3.83 ms	50%	A low MCS level provides the highest robustness, while a medium MCS level could be a good compromise between efficiency and performance.
2.2: HARQ	4.08 ms	60%	The maximum number of HARQ transmissions should be allowed to get the lowest latency.

PRB	Not available in the test infrastructure for downlink.	The parameter was not available in the downlink transmission direction in the infrastructure available for our test series.

5.3 Conclusions of the test series

All test series were performed as planned, despite disruptions to the time schedule resulting from Covid-19 restrictions on entering our test infrastructure facilities in Germany. Test results enabled us to define recommendations for each of the 5G radio network parameters which we studied for the SOGNO power network services.

5.3.1 Achieved latency improvements

To improve the latency of the SOGNO services transmitting data in a mobile network, optimizations in the radio configuration was performed. By using 5G technology, the latency could be lowered by up to 85.7% compared to the performance of 4G (LTE) systems. The performance of the 5G radio network was further optimized by testing a range of radio parameters that are related to transmission time. All of the investigated radio parameters showed an effect on the latency, which could be reduced by 44-81.25% by optimizing the parameters (see Figure 5.1). Eventually, an average latency in the uplink of 3.87-5.6 ms and 3.83-4.08 ms in the downlink was achieved.

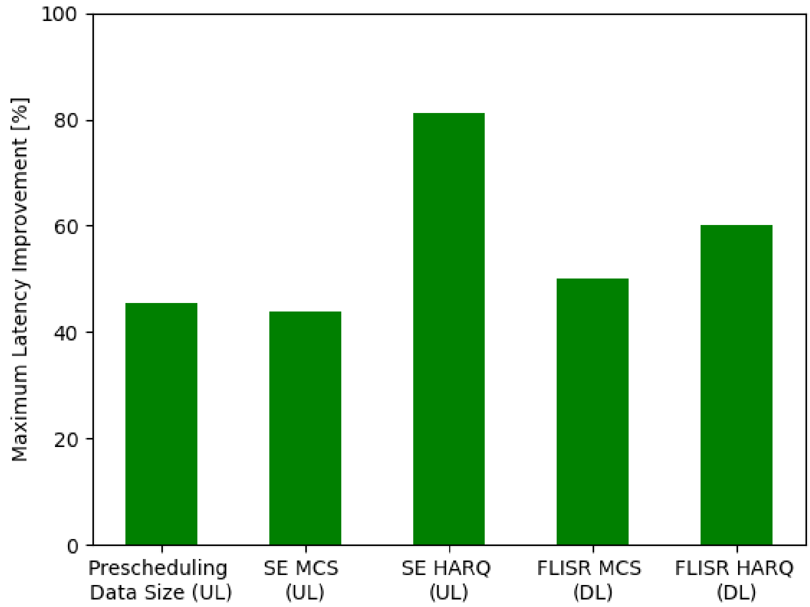

Figure 5.1 Latency improvement of optimized radio parameters in uplink (UL) and downlink (DL)

5.3.2 Performance of 5G in relation to ICT requirements for current and future SOGNO services

The current implementations of SOGNO services with **unidirectional** communication characteristic have relatively lenient requirements on the transmission time between sensor and control station. The **Power Quality Evaluation** and the **Load and Generation Prediction** services in this group do not have critical requirements on latency. The **State Estimation** service requires a maximum latency of 1 s.

In all tests with unidirectional traffic, the uplinks of the 4G and 5G networks were able to fulfill this requirement. However, lower latencies might be needed for future scenarios and enhanced versions of these services supporting near real-time digital management of the power grid.

The lower latency, achievable with 5G, is beneficial for faster visualization of the results which will enable the optimization of the efficiency of the power network in real-time and enable greater use of volatile energy generation sources reducing the CO_2 emissions of energy generation. Scenarios with dynamic voltage control, which require a fast interaction between the components of the grid rely on low latency. The recently started EdgeFLEX project [4], which builds on the SOGNO project results, provides examples of such scenarios. Additionally, it was tested, that a message period of 100 ms, which is shorter than the specified requirement for the State Estimation service, did not prevent the 5G radio network from meeting the latency requirement.

The SOGNO services with **bidirectional** communication characteristics are more latency critical and they require the superior performance of a 5G network. The requirement of 20-30 ms in latency for the **Power Control** service could be met in the 5G uplink and downlink direction after the radio parameters had been optimized. FLISR, which is the most time critical SOGNO service, requires a round-trip latency of less than 10 ms. The tests of uplink and downlink direction showed that average latencies in both directions of less than 5 ms could be achieved, so that the requirements on round-trip-latency of the **FLISR** service could be fulfilled.

It should be noted that the performance in the downlink direction is generally better than that of the uplink direction because of the effect of scheduling in the uplink. Downlink latency is usually lower than that of the uplink because scheduling is not performed in the downlink.

5.3.3 Recommendations on optimizations to minimize the latency of SOGNO services

The following recommendations on radio parameters were derived from the results of the test cases:

- **Prescheduling**: Uplink prescheduling should be enabled, and the prescheduling data size should be adjusted to the corresponding message size of the service
- **Modulation and Coding Scheme**: A low MCS level should be used, when the service requires low latencies with high robustness. For a higher network load, a medium MCS level can be used to serve both robustness and efficiency.
- **HARQ transmissions**: The latency can be optimized when the network allows more than 1 HARQ transmission. In that case, a retransmission can be made immediately after the potential transmission failure.
- **Number of PRBs**: A high number of PRBs should be allowed to use, because an insufficient number can cause high latencies due to network congestion.

The results and recommendations on optimizations of all test cases are summarized in the following Table 5.3.

Table 5.3 Summary of the results of all test cases in relation to SOGNO services

4/5G comparison and 5G radio network parameters	SOGNO Distribution Automation Services	Minimum average latency	Optimal settings in 5G radio networks to minimize latency
4G/5G Comparison	Power Quality Evaluation, Load and Generation	4.66 ms (uplink)	The 5G network can produce much better results than the 4G (LTE) network for these unidirectional services.

Prescheduling data size	Prediction and State Estimation	4.87 ms (uplink)	The prescheduling data size parameter should be larger than the message size of the service for these unidirectional services.
MCS		5.6 ms (uplink)	A low MCS level provides the highest robustness, while a medium MCS level could be a good compromise between efficiency and performance for these unidirectional services.
HARQ		3.87 ms (uplink)	The maximum number of HARQ transmissions should be allowed to get the lowest latency for these unidirectional services.
PRB		3.95 ms (uplink)	The maximum number of PRBs should be used to manage high network loads for these unidirectional services.
MCS	Power Control and FLISR	3.83 ms (downlink)	A low MCS level provides the highest robustness, while a medium MCS level could be a good compromise between efficiency and performance for these bi-directional services.
HARQ		4.08 ms (downlink)	The maximum number of HARQ transmissions should be allowed to get the lowest latency for these bi-directional services.

6. Conclusions of the 5G optimization study to minimize latency

This report gave an overview of the results that were collected in a number of test cases measuring the latency of the SOGNO services on communications links. Hereby, the objectives were reached. It was shown that 5G radio technology can meet the latency requirements defined for the SOGNO services. Additionally, a set of recommendations optimizing the performance of the radio link for these services were presented.

6.1 Main conclusions of our series of tests

The results of the tests, as described in Chapter 5, demonstrate that not only can 5G meet the requirements defined for the currently implemented use of the SOGNO services, but also that 5G can support the expected evolution of the SOGNO Distribution Automation Services as they evolve in coming years and place more challenging requirements on the latency of the communication networks used to support the services.

Furthermore, the results of the tests clearly show that SOGNO services performance over 5G radio network access can be further improved by optimizing the 5G radio access parameters in terms of minimised latency. In the tests, we investigated a set of radio access parameters which influence latency.

The analysis of the results allowed us to give recommendations on how the parameters should be chosen. The maximum number of PRBs should be used to manage high network loads. The prescheduling data size parameters should be larger than a message size of the service, which lowers the uplink latency by up to 45.5%. The MCS level should be rather low for a more robust communication. That results in a maximum reduction of latency of 44% in the uplink and 50% in the downlink compared to a higher MCS level. Allowing the maximum number of HARQ transmissions can decrease the latency by 81.25% in the uplink and by 60% in the downlink compared to limiting the number of allowed HARQ transmission to 1.

When the above described optimizations on the 5G radio parameters were implemented, the tests measured average latencies of 3.87-5.6 ms in the uplink and 3.83-4.08 ms in the downlink. Adding these values of uplink and downlink latency results in the average round-trip latencies of 7.7-9.68 ms. For the FLISR service, which is the most time critical service in this project with the most challenging requirements, SOGNO specified an expected round-trip latency of less than 10 ms. The tests proved, that the 5G mobile radio network can provide communications for the SOGNO services fulfilling the requirements for FLISR and all the other SOGNO services.

6.2 The value of our test results to a range of audiences

The recommendations on optimizations will be of interest to a wide range of organizations, each of whom can benefits from the results of this study. The value of our results for each sector addressed is described in Table 6-1 below.

Table 6.1: Value of our results to the organizations

Audience addressed by our results	Value of our results to the audience
5G system and device manufacturers	Our results and recommendations demonstrate the potential to optimize and reduce 5G latency in the radio network enabling them to support a wider range of utility and other vertical sector critical infrastructure use cases.
Public 5G network providers	Our results and recommendations demonstrate the potential to optimize and reduce 5G latency in the radio network enabling them to support a wider range of

	utility and other vertical sector critical infrastructure use cases.
Power network operators	Our results demonstrate that 5G has capabilities which can go far beyond the requirements of today's services for Distribution Network Automation. 5G can support the requirements of utility networks as services evolve towards enabling real-time optimization and management of power networks in the context of the increasing use of volatile renewable energy generation sources and the resulting need for real-time power grid management.
Power network system and device manufacturers and power network service providers	Our results demonstrate that existing and future latency requirements of power network services can be met using 5G networks and that optimizations of 5G radio networks offer improvements in latency to services with demanding latency requirements.
Academic institutions	Our results bring together the fields of communications and power network automation demonstrating how 5G mobile networks can offer flexible, low latency communications support for advanced cloud-based Distribution Network Automation services, such as those developed by the SOGNO project partners.

6.3 Future work

Further improvements in the 5G performance supporting the distribution automation services could be expected to be measurable in tests which could be undertaken in future projects, to evaluate the impact of the 5G Ultra Reliable Low Latency Communication (URLLC) service. Also, the performance of 5G measured with live power network service data could be tested. To investigate a shorter message period relevant for the Power Quality Evaluation service, the test equipment could be replaced with newer 5G end user devices and modems, which do not have limitations on message sending frequency.

Many of the results of the SOGNO project, including the 5G investigations, will be further developed in newly started H2020 projects, such as EdgeFLEX, which focusses on expanding the role of the Virtual Power Plants (VPP) with new power services supported by 5G and the IoT NGIN project (due to start in October, 2020) which focusses on the use of 5G to support advanced IoT use cases for energy, smart manufacturing and smart agriculture.

7. List of Tables

8. List of Figures

9. Bibliography

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10. List of Abbreviations

4G	4th generation mobile networks
5G	5th generation mobile networks
APMU	Advanced Measurement Unit
BBU	Baseband Unit
BLER	Block Error Rate
DL	Downlink
DSO	Distribution System Operator
eNB	Evolved Node B
FDD	Frequency Division Duplex
FLISR	Fault Location Isolation and Service Restoration
HARQ	Hybrid Automatic Repeat Request
ICT	Information and Communication Technologies
IP	Internet Protocol
LTE	Long Term Evolution
LV	Low Voltage
MCS	Modulation and Coding Scheme
MQTT	Message Queuing Telemetry Transport
mRRU	Micro Radio Resource Unit
MV	Medium Voltage
NB-IoT	NarrowBand Internet of Things
NTP	Network Time Protocol
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RES	Renewable Energy Sources
RRU	Radio Resource Unit
RTT	Round Trip Time
SE	State Estimation
SOGNO	Service Oriented Grid for the Network of the Future
TCP	Transport Control Protocol
TDD	Time Division Duplex
TSO	Transmission System Operator
UL	Uplink
URLLC	Ultra Reliable Low Latency Communication
ViSA	Virtualized Substation
VPN	Virtual Private Network
WP	Work Package