

edgeFLEX

D3.1

5G ICT requirements, development and testing for EdgeFLEX solution

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Abstract

In this deliverable, we first focus on the definition of the 5G context of the edgeFLEX services and enablers. We describe our definitions of the 5G ICT requirements of edgeFLEX services and enablers and of 5G-powered ICT solutions to optimally support them, as well as timescales for the commercial deployment of these solutions.

Then, in the context of edgeFLEX 5G-powered solutions, we describe the novel Ericsson prototype 5G Device Management Application Programming Interface (API) and how our demonstration of it shows the increased ease of use and increased security and flexibility which this API offers to VPP and power system operators. We developed a graphical user interface (GUI) for the 5G Device Management API to visualise the features of the API being used to support edgeFLEX services.

Keyword list

5G, ICT, 5G Device Management API, 5G capabilities exposure, edgeFLEX services, 5G solutions, URLLC, Network Slicing, edge cloud

Disclaimer

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

Executive Summary

This deliverable describes the results of a comprehensive study of:

- 5G ICT requirements of various edgeFLEX services and enablers,
- Potential 5G-powered solutions in commercial deployments,
- Ericsson's 5G Device Management Application Programming Interface (API) and its features, and the
- Development of the GUI to visualise the 5G Device Management API features.

EdgeFLEX developed new concepts for the following services: Voltage Control, Inertia Estimation, Frequency Regulation Metering, VPP Coordinated Frequency Control, VPP Automatic Generation Control, VPP Optimisation, Advanced Flexibility Trading and the edgePMU. Selected services were implemented and validated in both power and 5G laboratory tests and in the edgeFLEX field trials. Based on their professional experience of deploying voltage, frequency and inertia estimation services and providing solutions to their communication requirements, the experts in telecommunications and power grids of the project partners organised a series of discussions and workshops to define the estimated values of the parameters of the requirements.

The following 5G requirements were identified and described for each service: communication service availability, communication service reliability, maximum end-to-end latency, service bit rate, and transfer interval. All the services developed in the edgeFLEX project would benefit from the high levels of communication service availability and reliability that 5G networks can offer compared to legacy networks, whilst some of the services require the high availability which 5G can provide to operate correctly. In particular, the latency requirements of the edgePMU (the edgeFLEX enabler which places the highest requirements on latency) for less than 20 ms can be met by 5G, but not generally by 4G networks. 5G networks have capabilities meeting the latency requirements of all the edgeFLEX services. The requirements placed on both the 5G service bit rate and the transfer interval of edgeFLEX services are low, except for the requirements of the edgePMU which places high requirements on both parameters.

Various architectures and ownership models for 5G networks were investigated as potential solutions supporting the edgeFLEX services. Private, public and hybrid networks were considered using either edge cloud or central cloud. Service enhancements such as network slicing, the URLLC service and the proposed 5G device management API were considered. The assurance of the security of the edgePMU was given specific attention due to the limited processing power of the edgePMU device. The use of the eSIM solutions was considered as an alternative to the proposed 5G device management API to onboard devices to 5G networks. In addition, we investigated timescales and conditions for deployment of edgeFLEX services in commercial settings.

As the edgePMU places stringent requirements on 5G communications networks, we were able to define a new use case on acquisition of data in edge cloud and we successfully contributed this use case to the 3GPP global body responsible for 5G standardisations.

To improve the ease of use of 5G for energy providers and to reduce their need to interact with public 5G network operators, we have proposed the use of a novel prototype 5G device management API. The 5G features that would be beneficial to energy providers were identified based on the requirements of the edgeFLEX services. In addition, a demonstration frontend was created, which is an easy-to-use GUI that visualised integrated 5G device management API features.

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Table of Contents

1. Introduction	6
1.1 The edgeFLEX context of the work reported in this deliverable	6
1.2 Objectives of the work.....	6
1.3 Structure of this deliverable	7
1.4 How to read this deliverable.....	7
2. edgeFLEX services and enablers and their 5G context.....	8
2.1 Introduction	8
2.2 edgeFLEX services and their 5G context	8
2.3 edgeFLEX enablers and their 5G context.....	16
2.4 Summary of the communication characteristics of the edgeFLEX services and enablers	18
2.5 Conclusion of the section.....	19
3. 5G requirements for edgeFLEX services and enablers	20
3.1 Introduction	20
3.2 5G ICT requirements of edgeFLEX services and enablers	20
3.3 5G Device Management API requirements of edgeFLEX services and enablers.....	22
3.4 The impact of the physical locations of devices on the deployment of 5G for future commercial rollouts	24
3.5 Conclusion of the section.....	26
4. 5G solutions supporting edgeFLEX services and enablers and their commercial deployment aspects.....	27
4.1 5G solutions supporting edgeFLEX services and enablers.....	27
4.2 Timescales and conditions for deployments of edgeFLEX services in commercial rollouts with 5G	32
4.3 Global 5G standardisation contributions made by edgeFLEX.....	35
4.4 Conclusion of the section.....	35
5. The GUI developed for the 5G Device Management API	37
5.1 The development and functionality testing of the 5G Device Management API GUI ..	38
5.2 Conclusion of this section	43
6. Conclusions	45

7. List of Tables	47
8. List of Figures	48
9. References.....	49
10. List of Abbreviations	51
ANNEX.....	53

1. Introduction

This deliverable presents the work carried out in Work Package 3 (WP3) and the results of this WP in details, particularly Tasks 3.1 and 3.2. The deliverable focuses on Tasks 3.1 and 3.2 completed in both Phase 1 and Phase 2 of the edgeFLEX project. Phase 1 is the time period between the project start until the Month 12 of the project, whereas Phase 2 is the time period which starts from Month 13 and goes until the end of the project.

This deliverable describes the results of a comprehensive study on:

- 5G ICT requirements of various edgeFLEX services and enablers
- Potential 5G-powered solutions in commercial deployments
- Ericsson's 5G Device Management Application Programming Interface (API) and its features
- Development of the GUI to illustrate the 5G Device Management API features

1.1 The edgeFLEX context of the work reported in this deliverable

The deliverable is based on Tasks 3.1 and 3.2 of WP3. In general, Tasks 3.1 and 3.2 focus on defining the 5G requirements of edgeFLEX services and enablers and developing of a GUI for the 5G Device Management API with the aim to optimise Virtual Power Plant (VPP) operations.

1.2 Objectives of the work

The main objectives of the studies reported in this deliverable were to:

- Define the potential 5G ICT requirements of the edgeFLEX services and enablers,
- Define the potential 5G API requirements of the edgeFLEX services and enablers,
- Describe the edgeFLEX project efforts to standardize in 3GPP a use case and its requirements, derived from the architecture and capabilities of the edgePMU, enabling data acquisition in the cloud,
- Define and describe the potential 5G powered solutions in commercial networks that would meet the requirements of the edgeFLEX services as preparation towards exploitation of results, and
- Develop a GUI for the prototype 5G device management API to improve its usability and to demonstrate the increased ease of use which the 5G device management API offers to power system and VPP operators using 5G communications for power services.

After reading this deliverable, the reader will understand the:

- 5G context of the services and enablers developed in edgeFLEX,
- Successful 3GPP Standardization activities related to the edgeFLEX use case "edge cloud driven data acquisition", and
- 5G requirements of the edgeFLEX services and enablers which are described with the technical terms and definitions used in 3GPP to specify service requirements,
- 5G enabled solutions to the communications requirements of the edgeFLEX services and enablers and the potential timescales and constraints relevant for the deployment of the edgeFLEX services and enablers in commercial scale deployments supported by 5G networks,
- Context and functionality of the GUI of the prototype 5G Device Management API developed in the project to demonstrate how the 5G device management API offers

increased ease of use to VPPs and power system operators deploying the novel edgeFLEX edgePMU enabler.

1.3 Structure of this deliverable

First, this deliverable describes briefly the edgeFLEX services and enablers, and their 5G context in detail in Section 2. In Section 3, the 5G requirements of the edgeFLEX services and enablers are given and 5G Device Management API related requirements of these services are described with their 5G context. In addition, the conditions of physical locations of the device deployments in the field trials are described in this section. The 5G solutions fulfilling the requirements of each edgeFLEX service and enabler are defined and described. The expected timescales for the deployment of edgeFLEX services in commercial networks are described in Section 4. The development of a GUI for the novel 5G Device Management API is described in Section 5. Finally, the conclusions regarding the work described in this deliverable is given in Section 6.

1.4 How to read this deliverable

This deliverable is the first detailed description of the 5G aspects in edgeFLEX project. Therefore, the deliverable can be read on its own. However, the edgeFLEX services and enablers provided in this deliverable is a summarised version of the detailed definitions provided in other deliverables. The detailed descriptions of these services can be found in deliverables from WP1-3. In addition, the deliverables from WP4 will give an overview of the overall edgeFLEX architecture and more details of the 5G Device Management API, which would help readers to follow this deliverable better. The following deliverables form a basis on which this work described in this deliverable is built:

- “D1.1: Scenario description for dynamic-phasor driven voltage control for VPPs” and “D1.2: Dynamic-phasor driven voltage control concept for current VPPs in large scale deployment” provide the detailed descriptions of the voltage control service, which is summarized in this deliverable in Section 2.2.1 [1] [2].
- “D2.2: Frequency control concept for current VPPs in large scale deployment” provides the detailed descriptions of the frequency control services, which are summarized in this deliverable in Sections 2.2.3, 2.2.4 and 2.2.5 [3].
- “D2.4: Inertia estimation concept for low inertia power system” provides the detailed descriptions of the inertia estimation service, which is summarized in this deliverable in Section 2.2.2 [4].
- “D3.2: Report on VPP optimisation” provides the detailed descriptions of the VPP optimisation service, which is summarized in this deliverable in Section 2.2.6 [5].
- “D4.1: Description of edgeFLEX platform design” provides the detailed descriptions of the edgeFLEX platform, its components and architecture developed in the project. In addition, the details of advanced energy flexibility aggregation and trading system can be read in there, which is summarized in this deliverable in Section 2.2.7 [6].
- “D4.2: Description of edgeFLEX MVP” provides the detailed descriptions of the edgeFLEX minimum viable product, which builds on top of D4.1. In here, a functional architecture was designed to capture all elements of the edgeFLEX platform, data collection and communications, and various 5G solutions described that can support the edgeFLEX platform [7].
- “D4.3: Description of internal interfaces for control services” provides the details of 5G Device Management API, its features, and its benefits to the edgeFLEX control services, and various deployment options of edgeFLEX components including the 5G Device Management API [8].

2. edgeFLEX services and enablers and their 5G context

2.1 Introduction

In this section, the functionality of the edgeFLEX services and enablers and their communication characteristics are summarised and our investigations of their 5G context is described. In our investigations, we focus on using 5G and edge cloud with the edgeFLEX services. Some of the edgeFLEX services do not necessarily need the capabilities 5G offers such as low latency or high availability and will work with the capabilities of older cellular networks such as 4G. The services could be hosted locally in an edge cloud increasing the resilience of the power network and reducing the latency of communications. Details of the edgeFLEX services can be found in deliverables D1.1, D2.2, D2.4 and D3.2.

In addition to the 5G context of the edgeFLEX services and enablers, network solutions supporting fail-safe operations for cloud-based applications, should the synchronisation of the edge cloud with the central cloud fail, were investigated and defined.

2.2 edgeFLEX services and their 5G context

This section provides a brief overview of the edgeFLEX services using 5G and edge cloud. The focus is on the communication aspects of the services. Services which do not require 5G and edge cloud are outside the scope of the present deliverable.

The terminology used in mobile communication networks is based on the communication direction. The term “uplink” describes when an end device, such as a sensor or a smart phone, communicates with an application deployed in the mobile network. In contrast, “downlink” describes the communication from the mobile network to the device. Communication means that data streams are transmitted between mobile network and end device and vice versa. Depending on which communication direction is used, different techniques and resource parameters are assigned to the data streams. Some of the edgeFLEX services require only uplink communication classified as unidirectional power network services in this deliverable such as Inertia Estimation. For instance, Voltage Control, Frequency Control or VPP optimization require both uplink and downlink communication and are classified as bidirectional power network services in this deliverable.

2.2.1 Voltage control Service

The voltage control (VC) service has the goal to balance and regulate the electrical grid in terms of voltage stability. Therefore, the service decreases the risk of disconnection of distributed generators and interruptions. VC uses voltage and power measurements from field devices installed in the electrical grid operated by a DSO. Measurements are performed periodically and sent via the communication link to the VC algorithm deployed in an edge cloud that should be physically collocated with a secondary substation. It analyses the data to calculate new setpoints of active and reactive power in a centralized manner using real-time processing. The algorithm is checking the voltage stability constantly to avoid overvoltage or undervoltage. Edge cloud capabilities are needed to deploy and run the algorithm close to the devices to decrease the latency. Specific communication protocols are not required. Finally, the setpoints are sent back in the control stream via the communication link to the actuators (field devices) to change the state of the VPP assets. The corresponding service diagram is shown in Figure 2-1.

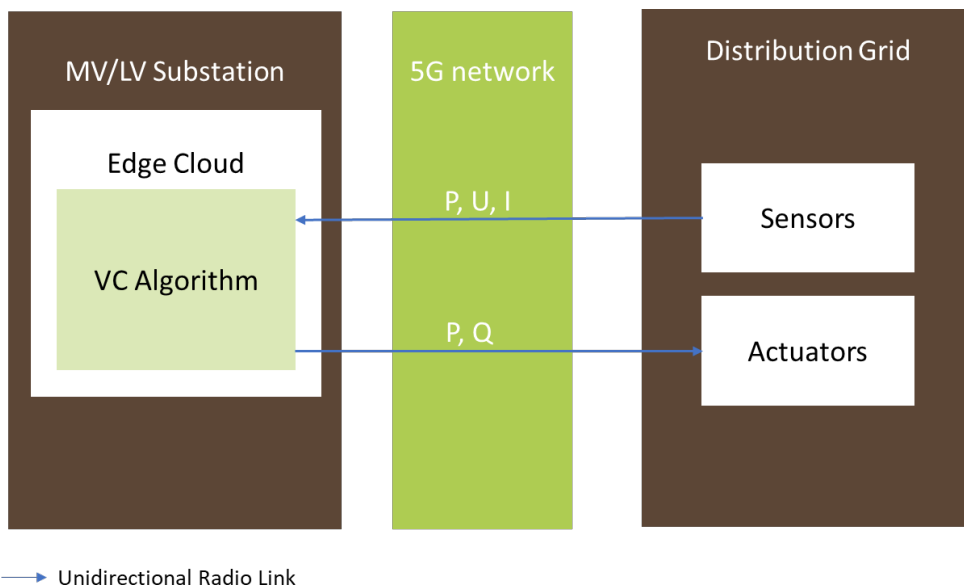


Figure 2-1: Voltage Control Service Diagram

VC can be summarized in the following steps:

- Phasor measurement units measure current and voltage values from the grid, whereas smart meters measure power values. The measurements are taken periodically and are sent to the VC algorithm.
- The VC algorithm deployed in the edge cloud and operated by the DSO receives the measurements. Then, it computes the amount of overvoltage or undervoltage resulting in set points.
- The actuators receive the setpoint and change the state of the DSO asset.

Table 2-1: Voltage Control Service Overview

Voltage control service	
Goal	Balance and regulation of the electrical grid in terms of voltage stability
Input to VC algorithm	Monitoring stream (uplink) of voltage and current measurements from sensors
Output	Control stream (downlink) of setpoints to change DSO assets

2.2.2 Inertia estimation Service

Inertia estimation (IE) aims to monitor the system’s inertia and is critical especially in a non-regulated and uncertain environment. Nowadays, the system operator is increasingly unsure of how much inertia is available at any point in time in the power network because of the increasing number of renewable sources in the network which do not have significant inertia, and the fact that inertia cannot be measured. The edgeFLEX inertia estimation service uses the frequency and power measurements of devices providing inertial response, as well as the reference power signal available at the system operator (SO). The measurements need to be time stamped and to be stored in SO control centre, because the inertia estimation relies on post-processing of measurements. The source of the frequency and power measurements are Phasor Measurement Units (PMUs) and power meters deployed in Medium Voltage (MV) substations. The data is sent periodically as a monitoring data stream via the 5G link to the centralized IE algorithm located in the SO’s control centre. The output is a single estimated value of the overall system inertia and is shown to the SO. The communicating elements of this service is visualized in Figure 2-2.

An accurate estimate of inertia helps the SO to assess the health of the system. Depending on the inertia being low or critical, the SO will take proper actions in terms of system planning and operation, e.g., unit commitment or fast frequency reserve procurement (if already regulated) etc. Furthermore, the inertia acts as an energy buffer, so that it can slow down the frequency dynamics in case of a disturbance in the system. In addition, the SO can use IE in contingency studies or use it in other applications and take decisions.

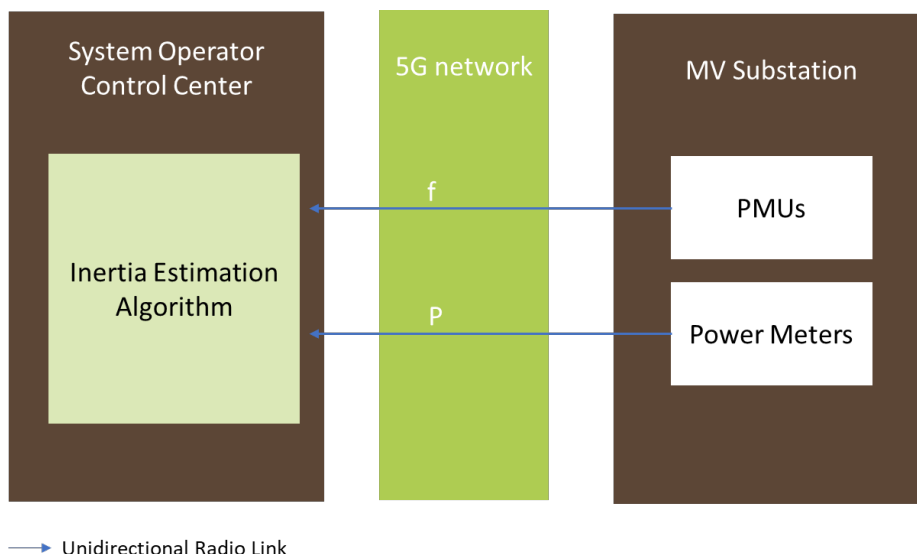


Figure 2-2: Inertia Estimation Service Diagram

The inertia estimation service can be summarized in the following steps:

- Phasor measurement units and power meters measure power and frequency from the medium voltage substations.
- The measurements are sent via the 5G link to the SO’s control centre in which the inertia estimation algorithm is hosted. The algorithm is executed and results in a single inertia value shown to the SO.
- The SO takes proper action.

Table 2-2: Inertia Estimation Overview

Inertia estimation service	
Goal	Monitor system’s inertia in unregulated and uncertain environment
Input to IE algorithm	Frequency and power measurements
Output	Single value of the estimated inertia

2.2.3 Frequency Regulation Metering Service

Being a part of the monitoring services in frequency control services, the purpose of the metering service is to check if the device in Distributed Energy Resources (DER) provides fast frequency regulation (FFR). FFR is the solution that adjusts the output active power of the device proportionally to the frequency deviation. The solution provides frequency support from DERs within less than 1s. The solution applies on device level, i.e., DERs. edgeFLEX services assume that the solution is implemented in the system at device level. The input is based on frequency measurements collected from non-synchronous generators (from DERs), i.e., from their neighboring buses. The service runs in the TSO control centre, analyses the measurement, and provides the Rate-of-Change-of-Power (RoCoP) of the device. It could be run on DSO level in future as well. The output is given to the operator indicating if the device uses frequency regulation

or not. The time scale of the services is short in a range of seconds, between 1s and 5s. The service diagram is displayed in Figure 2-3.

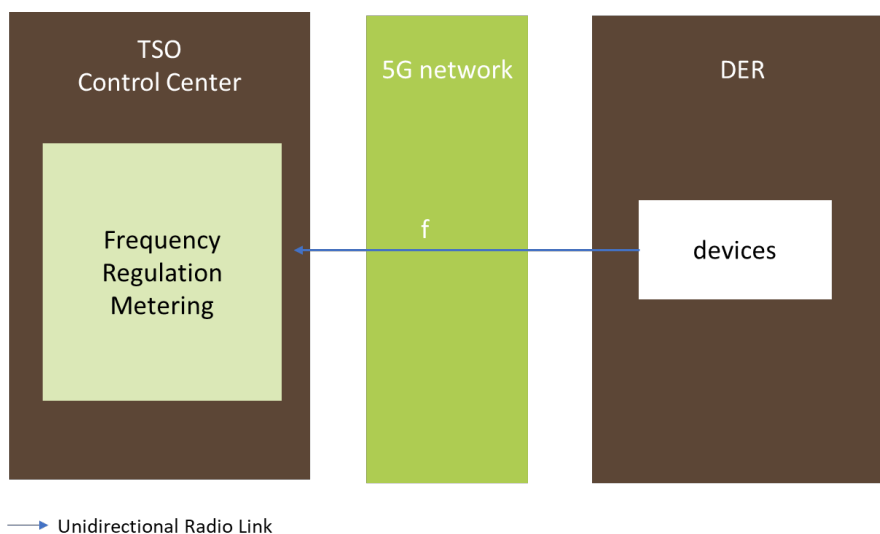


Figure 2-3: Frequency Regulation Metering Service Diagram

The service’s steps are summarized:

- Devices send the frequencies measured in DERs to the frequency regulation metering service at TSO control centre.
- The service located in TSO control centre computes RoCoP based on the provided measurements.
- The system operator receives RoCoP indicating if the device provides FFR or not.

Table 2-3: Frequency Regulation Metering Service Overview

Frequency regulation metering service	
Goal	Check if device in DER provides FFR or not
Input	Frequency measurements of devices
Output	RoCoP indicating if the device provides FFR or not

2.2.4 VPP Coordinated Frequency Control Service

VPP coordinated frequency control is a control service in frequency control services. Its goal is to coordinate the devices (DERs) that provide FFR and that compose VPP. Measurements of devices should be communicated within 1s of the measurement being made. The whole service algorithm defining new set point needs to execute and deliver the new set points to the devices within 30s (0.5s – 30s). The service is developed in edgeFLEX and is intended for VPPs to use. The VPP assets are coordinated in a centralized way.

The service takes two measurements as inputs. First, it uses active power injected into the grid by the VPP (injected power at the bus which interfaces VPP with the rest of the network). Secondly, it uses the grid frequency which is measured at the point of connection (POC) of the VPP. These measurements are transmitted in a monitoring data stream (uplink) to the service in the VPP’s operator centre. It generates the output being setpoints (control signal). A control stream is sent back to the renewable energy resources and storages. Local control in DERs will act based on the new reference (setpoint received from the service). A visualization is given in Figure 2-4.

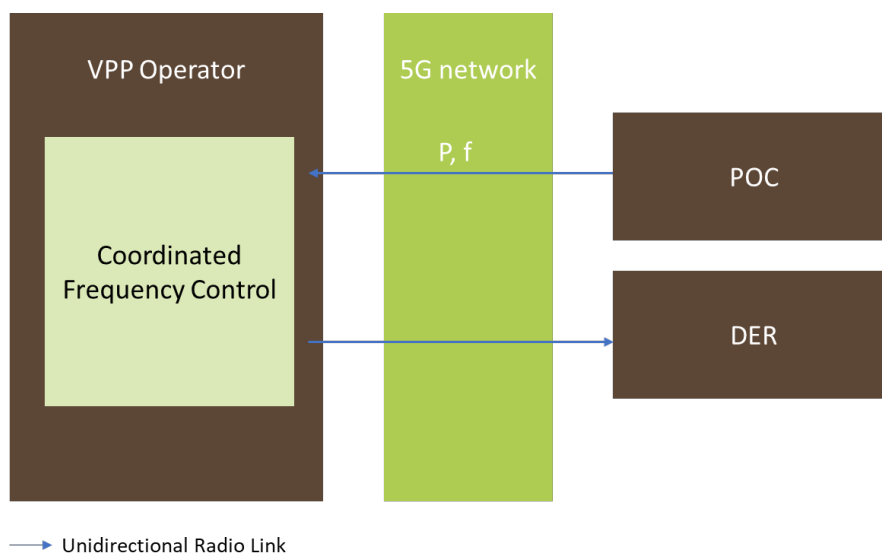


Figure 2-4: VPP Coordinated Frequency Control Service Diagram

The service is summarized in the following parts:

- Power and frequency measurements are sent from POC of the VPP to grid.
- The algorithm in the VPP’s operator centre computes set points.
- Setpoints are sent back to DERs which compose the VPP.

Table 2-4: VPP Coordinated Frequency Control Service Overview

VPP coordinated frequency control service	
Goal	Coordination of devices providing FFR to stabilize system
Input	Monitoring data (uplink) stream with power and frequency
Output	Control stream (downlink) with setpoints

2.2.5 VPP Automated Generation Control Service

VPP Automated Generation control or Automatic Generation Control (AGC) is another control service in the frequency control services. It is intended to be used by VPP operators for the regulation of the grid frequency. AGC which operates in a centralized manner aims to restore the grid frequency to the nominal value and keep the VPP power injection at the scheduled value. The service uses as an input the reference power signal sent by the TSO and the power injections of all DERs which compose the VPP. As a presumption, DERs provide FFR or Virtual Inertia. By using power injections from DERs that compose VPP and reference power signal from TSO in a control algorithm, the service sends back modified setpoints (control signal) to DERs. The time scale within which the service needs to collect input data, calculate new set points and deliver them to devices is above 30s and can be up to 15min. A graphical overview of AGC is given in Figure 2-5.

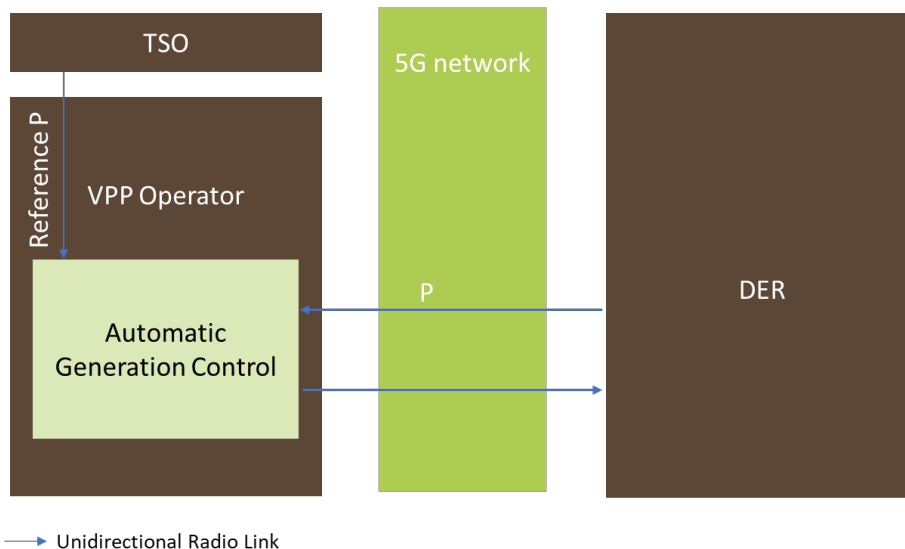


Figure 2-5: VPP Automated Generation Control Service Diagram

The service can be described by the following steps:

- Reference power signal from TSO and the power injections of all DERs which compose the VPP are sent to AGC.
- AGC computes setpoints.
- Setpoints are sent back to DERs.

Table 2-5: VPP Automated Generation Control Service Overview

VPP automated generation control service	
Goal	To bring the power grid frequency to nominal value and keep the VPP power injection at the scheduled value
Input	Monitoring stream (uplink) with reference power signal from TSO and the power injections of all DERs which compose the VPP
Output	Control signal (downlink) with setpoints

2.2.6 VPP Optimisation Service

The goal of VPP Optimisation Service is to save VPP owner costs based on optimization logic, forecast and stochastic model. The service will decrease the costs of the VPP when there is no imbalance in the grid and decrease them further when there is an imbalance. VPP optimization is nowadays a centralized service, which is evolving to become a distributed service with the advantages that single points of failure are avoided and that service instances can communicate among themselves.

The service is fed by the forecast and stochastic model and needs the following data: tasks from the system operator, flexibility schedules, weather information (actual and forecast), metadata (parameters) of the assets in the pool, output of stochastic model and energy prices. The weather forecast data collected from online web services or temperature sensors installed at the VPP premises is provided to the optimization algorithm every 15 minutes. The energy prices collected from the energy market, to which an interface is established, will be used as input for the stochastic model.

In the uplink, a monitoring data stream is sent to the service algorithm in the edge cloud via an IoT gateway. The stream contains aggregated measurements collected from the sensors (VPP assets). The sensors are usually connected by cables to the gateway and communicate with the gateway based on an industrial protocol such as Modbus. The IoT gateway is placed onsite/edge in a SCADA system to provide a wireless communication channel between the sensors and the cloud. This gateway might not be necessary, if there are other solutions in place for delivering the real-time measurements to the algorithm in the cloud. Therefore, it is not displayed in the service diagram. The algorithm subscribes to the real-time data stream published by MQTT broker and processes it. The output of the VPP optimisation algorithm is a production schedule as setpoints. In the downlink, a control data stream is transmitted from the edge cloud to the VPP assets. The IoT gateway that is subscribed to the control streams news, gathers the data received from the cloud, converts the control signal into an industry protocol such as Modbus, and sends it to the SCADA controller and effects the change on the on-site equipment. In Figure 2-6, the corresponding service diagram is shown.

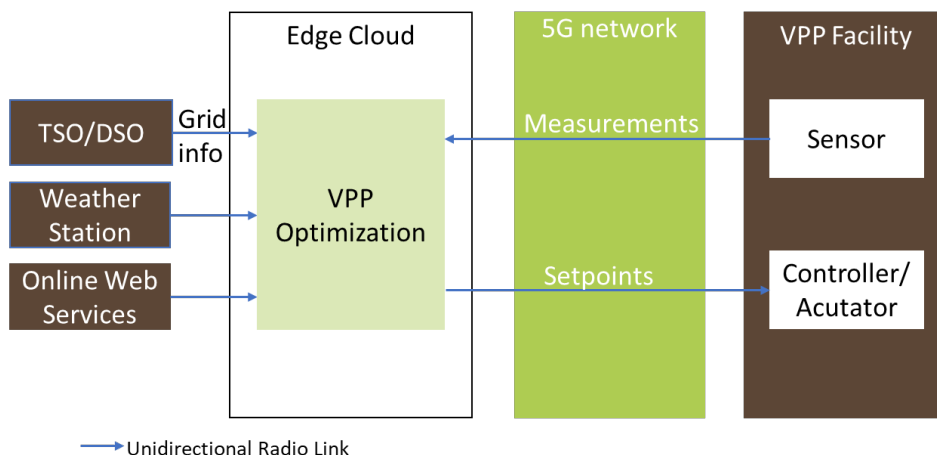


Figure 2-6: VPP Optimisation Service Diagram

The VPP optimization service can be summarized in the following steps:

- Sensors of the VPP take measurements.
- The measurements are sent via a wired Ethernet connection to an optional IoT gateway using the Modbus protocol (not shown in Figure 2-6 diagram).
- The IoT gateway forwards the data via a 5G link to the edge cloud using the MQTT protocol. It is currently implemented in the VPP facility. In future scenarios, it might be not used anymore.
- The VPP optimization algorithm running in the edge cloud receives the measurements of the monitoring data stream. In addition, it receives grid information from the TSO/DSO, information from online web services and weather forecasting.
- The algorithm computes set points which are sent back to the IoT gateway via the 5G link as control data stream using MQTT.
- The IoT gateway converts the control stream to an industry protocol and sends it to controllers.
- The actuators receive information from the controllers and change the equipment.

Table 2-6: VPP Optimisation Service Overview

VPP optimisation service	
Goal	Financial tool to optimize VPP operations

Input	Monitoring stream (uplink): tasks from the system operator, flexibility schedules, weather information (actual and forecast), metadata (parameters) of the assets in the pool, output of stochastic model and energy prices
Output	Control commands on the VPP assets sent as a stream (downlink): setpoints

2.2.7 Advanced Energy Flexibility Aggregation and Trading Service

Today's congestion management and grid balancing do not include any flexibility or trading opportunity. To overcome this issue, the scope of this service is to manage and to trade flexibilities by introducing the GOFLEX system and by running control algorithms that allow fast frequency, inertia, and voltage control. It is achieved by providing congestion management and DSO grid balancing by using flexibility (currently done by the TSO, in the future it might be the DSO), postponement of investments (to save money) and management of voltage excursions using reactive power control.

There are two sub use cases of this service: Automatic Flexibility Trading and Reactive Power Trading and Management. The scope of the latter is to mitigate the predicted event (i.e., reactive energy or energy trading), if all other methods, such as classic market balancing and automatic flexibility trading, fail. The service works in a centralized (DSO-centric) manner and uses flexibility offers. The trading means the energy trading among prosumers, and the management applies to the grid management conducted by the TSO and DSO. EdgeFLEX services such as voltage and frequency control services can be considered as a part of this use case.

A Flexibility Offer Agent (FOA) collects the data relevant for trading locally from the controllable devices, sensors, meters, actuators, and Energy Management Systems (EMS) and provide the trading information to the Flexibility Trading Platform (FTP) in the form of the FlexOffer (FO). FOA is usually serving a single device, e.g., heat pump or other loads that have thermal capacity. Then, the data is collected locally (typically on embedded hardware) and processed, and the information relevant for the trading is prepared. After the flexibility aggregation platform aggregates the data from FOA in a public 5G network, this so-called operational information is sent to the flexibility market receiving additional information by the DSO. The Flexibility Trading Platform collects, manages and trades flexibilities from participating prosumers. It generates and shares operating schedules to FOAs. Finally, FOAs execute received schedules by control of underlying devices every five minutes on average. An overview of this service is given in Figure 2-7.

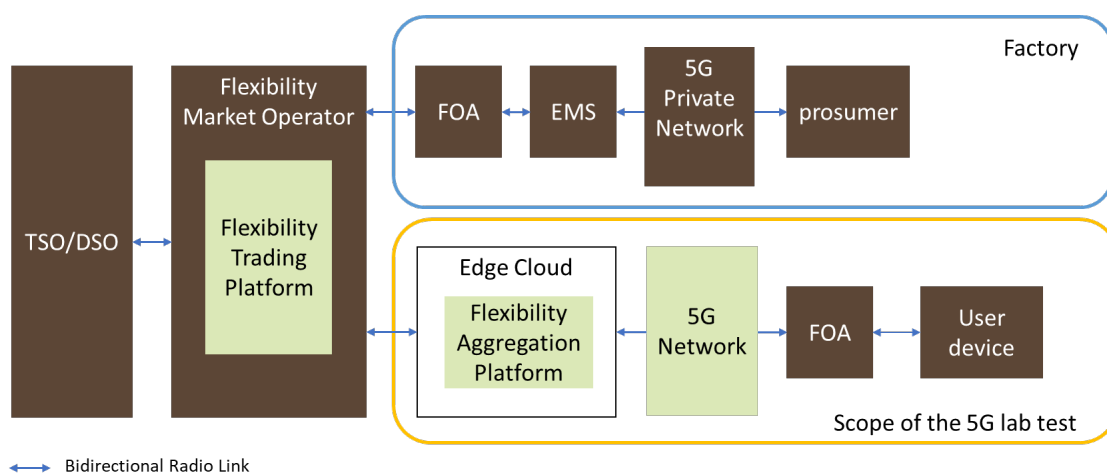


Figure 2-7: Advanced Energy Flexibility Service Diagram

The service can be summarized in the following steps:

- Provision of operational information from prosumers' end devices and the power grid to the flexibility trading platform by

- FOA, which collects data relevant for trading from prosumers such as sensors, meters, actuators, and EMS in the form of FlexOffers,
- Flexibility aggregation platform, which aggregates data from different FOAs and contributes to power trading using public 5G networks for communications, and
- TSO/DSO, which is responsible for the grid management.
- Flexibility trading platform collects and manages FlexOffers from FOAs. It generates and shares back operating schedules to FOAs.
- FOAs execute received schedules by control of devices.

Table 2-7: Advanced Energy Flexibility Service Overview

Advanced energy flexibility aggregation and trading system	
Goal	Manage and trade flexibilities to balance the market using intraday and reserve mechanisms
Input	Operational data relevant to energy trading from prosumers end devices and the power grid (uplink): data from controllable devices, sensors, meters, actuators, and EMS systems
Output	Operating schedules (downlink)

2.3 edgeFLEX enablers and their 5G context

2.3.1 edgePMU

To measure electrical quantities from the grid, e.g., voltage and current amplitude or frequency, phasor measurement units (PMUs) can be used. The measurements are taken with a timestamp synchronized to a global time, such as GPS, enabling real-time monitoring. Then, those measurements are given as inputs to the services such as the state estimation or voltage control.

To offer higher flexibility in terms of remote update of the device software and the easy integration of new advanced functions as well as to save costs, the data acquisition and the processing can be separated. Following this approach, the PMU just takes sampled time-stamped measurements, and the processing is moved in the edge cloud. This separation introduces the concept of the edgePMU [9].

To use the edgePMU, some preparation must be undertaken. The voltage or current measurement sensor or both sensors must be deployed with the data acquisition unit (DAQU) in the power grid. Full 5G network coverage must be ensured over the area in which the data is collected. The DAQU is connected wirelessly to the edge cloud which hosts the algorithm, e.g., the phasor calculation. A service diagram of this enabler is shown in Figure 2-8.

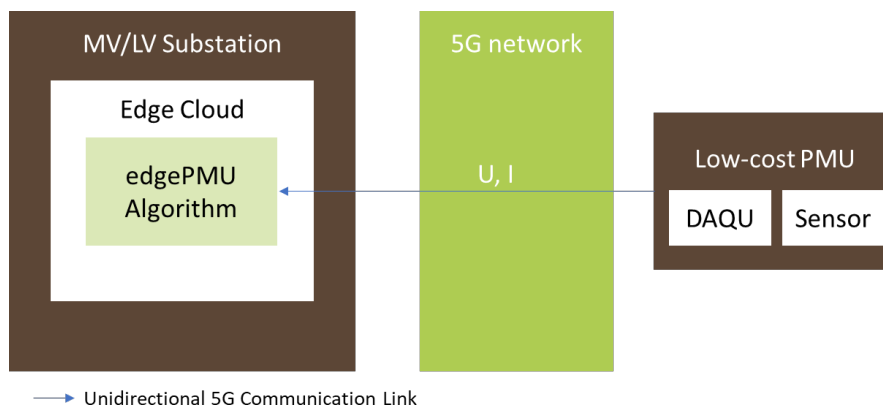


Figure 2-8: edgePMU Service Diagram

The edgePMU enabler is summarized in the following steps:

- Data is acquired by the low-cost PMU such as voltage or current amplitudes.
- The measurements are sent via a 5G communication link to the edgePMU algorithm hosted in the edge cloud.
- The algorithm processes the data.
- The processed data can be forwarded to other applications or actors inside or outside of the edge cloud.

Table 2-8: edgePMU overview

edgePMU	
Goal	Low-cost real-time data monitoring
Input	Voltage and/or current measurements
Output	Processed data, e.g., calculated phasor

2.3.2 5G Device Management API

As 5G becomes more widely adopted in various industrial sectors, the importance of exposing the capabilities of 5G to the users and developers in these sectors increases. By exposing the 5G capabilities to the users, the complexity of 5G networks can be hidden, allowing faster development of the industrial services and faster adoption of 5G into industrial infrastructure which reduces the costs of implementing the services with 5G.

In edgeFLEX, we have a particular focus on exposing the device management capabilities of 5G networks through an Application Programming Interface (API). The 5G Device Management API is used in edgeFLEX to address the relevant requirements of edgeFLEX services and enablers defined during the project, and the power system operators and VPP operators in general. As an exemplary benefit of this API, developers from a DSO can manage the connectivity of their devices through the API provided to them without spending time to learn complex 5G mechanisms.

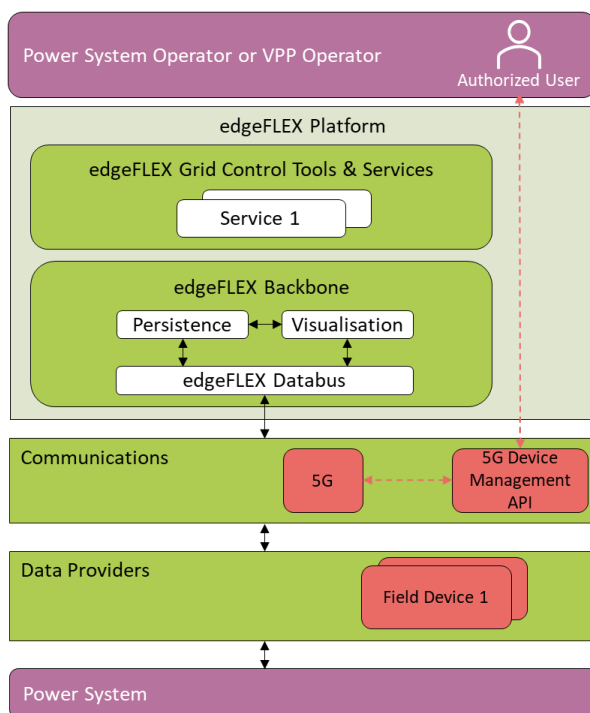


Figure 2-9: An exemplary edgeFLEX Functional Architecture with the 5G Device Management API

To illustrate where the 5G Device Management API is in the edgeFLEX architecture, and what other edgeFLEX components could be in place, an exemplary architecture diagram can be drawn, as in Figure 2-9. As seen in the diagram, the types of operators, grid services or data providers are not specified, since the procedures of the API for each operator, either a DSO or a VPP operator, are identical. As an example, we consider that the API will be used by an operator (a DSO or a VPP operator), who uses 5G as the communication technology and owns a power system. Additionally, the operator should have its field devices deployed in the power system and have some components from the edgeFLEX platform [6] [7] deployed on their premises. For instance, these components can be an edgeFLEX grid control service such as voltage control, and the edgeFLEX backbone such as data bus, persistence, and visualisation. In addition, there needs to be a person working at the operator, who is given authorization to use the 5G Device Management API to request various operations to be executed in the 5G network. The boxes and arrows in the diagram related to the API as well as the field device boxes are shown as pink, because the operations requested from the API are effectively related to the connectivity of field devices.

After having defined the roles of the necessary actors and edgeFLEX components, the functionality of some of the operations that a user can perform can now be explained. For instance, when there are 5G-capable field devices available in the power system, the authorized user can send a request to the API to provide and onboard those devices to the 5G network. This action can be done by simply providing the SIM card details of the 5G-capable field devices. As a result, the field devices are connected to the 5G network and have the communication links created with default Quality-of-Service (QoS) parameters. The user can send another request to the API to change the QoS parameters of a communication link from default to higher values, in case it is necessary for a particular device e.g., to send larger quantity of the data that would require more bandwidth. As a result, the communication link is adapted to support the data transfer with high bit rate. If the user wants to check the quality and the status of this new communication link of that device, the user can send a new request to the API. As a result, the user monitors the quality of the current communication link in terms of e.g., packet loss or latency.

There are many device-connectivity related operations, some of them mentioned above, which can be executed by an authorized user by sending corresponding requests to the 5G Device Management API. After receiving the user requests with relevant information, the 5G Device Management API modifies them in a way that the 5G network functions can process. Then, it forwards the modified requests to the corresponding 5G network functions to perform the operation in the 5G network. Finally, the API sends a response back to the user stating whether or not the operation was successfully performed in the 5G network.

2.4 Summary of the communication characteristics of the edgeFLEX services and enablers

The following Table 2-9 gives a summary of the communication characteristics of the edgeFLEX services and enablers.

Table 2-9: Communication characteristics of the edgeFLEX services and enablers

	Goal	Input	Output
Voltage Control	Balance and regulation of the power grid in terms of voltage stability	Monitoring stream (uplink): voltage and current measurements from sensors	Control stream (downlink): setpoints to change VPP assets
Inertia Estimation	Monitor system's inertia in unregulated and uncertain environment	Frequency and power measurements	Single value of inertia

Frequency Regulation Metering	Check if device in DER provides FFR or not	Frequency measurements of devices	RoCoP indicating if device provides FFR or not
VPP Coordinated Frequency Control	Coordination of devices providing FFR to stabilize system	Monitoring data (uplink) stream: power and frequency	Control stream (downlink): setpoints
VPP Automatic Generation Control	Grid frequency to nominal value and VPP injection at scheduled value	Monitoring stream (uplink) with reference power and power injections of DER	Control signal (downlink): setpoints
VPP Optimisation	Provide better financial outcome to the VPP asset owner	Monitoring stream (uplink): tasks from the system operator, flexibility schedules, weather information (actual and forecast), metadata (parameters) of the assets in the pool, output of stochastic model and energy prices	Control stream (downlink): setpoints
Advanced Energy Flexibility Aggregation and Trading Service	Manage and trade flexibilities to balance the market using intraday and reserve mechanisms	Operational information (uplink): data from controllable devices, sensors, meters, actuators, and EMS systems	Operating schedules (downlink)
edgePMU	Low-cost real-time data monitoring	Voltage and/or current measurements	Processed data, e.g., calculated phasor

2.5 Conclusion of the section

Our investigations on the 5G context of edgeFLEX services and enablers, based on examining the communication characteristics of the edgeFLEX services and enablers, allowed us to understand what kind of data is being communicated between the endpoints of each edgeFLEX service. Furthermore, our studies on the 5G Device Management API and the requirements of edgeFLEX services related to the API showed that the edgeFLEX services and the power operators could benefit from the 5G Device Management API through increased ease of use of 5G networks.

3. 5G requirements for edgeFLEX services and enablers

3.1 Introduction

This section defines and describes 5G ICT requirements of the following edgeFLEX services and enablers: voltage control, inertia estimation, frequency regulation metering, VPP coordinated frequency control, VPP automated generation control, VPP optimization, energy flexibility trading and edgePMU. The 5G ICT requirements of the edgeFLEX services and enablers were determined in collaboration with the project partners. Apart from the 5G ICT requirements, the requirements of edgeFLEX services and enablers on the 5G Device Management API were also investigated and described in this section. As a result of these investigations, various 5G Device Management API related requirements were defined, and they were mapped to the features of the API. The details of these requirements are given in Annex A.1 and the detailed descriptions of the novel 5G Device Management API can be found in deliverables D4.1, D4.2 and D4.3.

3.2 5G ICT requirements of edgeFLEX services and enablers

In this section, an overview of the 5G ICT requirements of edgeFLEX services and of one edgeFLEX enabler, namely the edgePMU, is provided. The detailed definitions of 5G ICT requirements of edgeFLEX services and of the edgePMU is provided in Annex A.1.

Based on their professional experience of deploying voltage, frequency and inertia estimation services and providing solutions to their communication requirements, the experts in telecommunications and power grids of the project partners estimated the values of the parameters of the requirements. The values described in Table 3-1 below define the communication requirements of the edgeFLEX services are likely to have if they would be deployed today in commercial power grid networks. In future deployments, the collection of higher volumes of data at increasingly shorter time intervals is expected to further improve the precision of edgeFLEX services. Accordingly, the communication requirements can be expected to become more and more stringent as the power grid management moves towards a close to real-time approach.

The following assumptions were made as a basis for the definition of the 5G ICT requirements:

- All requirements were defined in the context of future large-scale edgeFLEX service deployments with the support of wide area wireless communication networks, rather than defining the requirements in the context of the small-scale deployments in the edgeFLEX field trials.
- We assumed that neither a fallback communications link, in case of loss or degradation of the communications links, nor redundancy of links is provided by the communications system in which the services are deployed.

The devices required for edgeFLEX services (sensors and actuators) will be deployed through wide geographical areas in future large-scale commercial deployments of services. The geographical distribution density of the deployed devices in power networks will depend on the specific service architecture required for specific deployments. Generally, the density of devices will be low. In extreme cases, it will be less than 10 devices per square kilometre. The services do not require a massive number of devices to function correctly. The total number of devices per service will be under one thousand devices. The geographic region where communication service will be accessible for the service will vary from several square kilometres up to 100,000 square kilometres.

For each of above mentioned edgeFLEX services and enablers, the following requirement parameters were considered. The definitions of parameters provided below are taken from 3GPP standards.

- **Communication Service Availability:** percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the

specification in a specific area. The end point in "end-to-end" is the communication service interface. The communication service is considered unavailable if it does not meet the pertinent QoS requirements and an expected message is not received within a specified time, which, at minimum, is the sum of end-to-end latency, jitter, and survival time [10].

The communication service availability depends on the latency and reliability of the logical communication link, as well as the survival time of the cyber-physical application as stated in [11]. The survival time is the time that an application consuming a communication service may continue without an anticipated message [10].

In this deliverable, the communication service availability is described by the number of nines which correspond to a specific time of unavailability, e.g.,

- '7 nines' means downtime per month of 300 milliseconds.
 - '6 nines' means downtime per month of 3 seconds.
 - '5 nines' means downtime per month of 26 seconds.
 - '4 nines' means downtime per month of 4 minutes.
 - '3 nines' means downtime per month of 43 minutes.
- **End-to-End Latency:** the time that takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination [10].
 - **Service bit rate (aka. user experienced data rate):** the minimum data rate required to achieve a sufficient quality experience, with the exception of scenario for broadcast like services where the given value is the maximum that is needed. [10]
 - **Transfer interval:** time difference between two consecutive transfers of application data from an application via the service interface to 3GPP system. [11]

The 5G ICT requirements of considered edgeFLEX services and enablers are depicted in Table 3-1. The requirements of edgeFLEX services and enablers are elaborated in detail in Annex A.1.

That 5G could fulfil the latency performance requirements of the edgeFLEX services was tested and verified in a 5G laboratory and has been reported in D5.5. The requirements placed by the edgeFLEX services on the 5G communications bit rate and transfer interval were defined by the project partners as input to the service communication performance tests in the laboratory. It was not possible to test the 5G communications availability and reliability requirements of the services with the laboratory infrastructure available in this project.

Table 3-1: 5G ICT requirements for edgeFLEX services and enablers

	Comm. Service Availability	Maximum End-to-End Latency	Service Bit Rate [kbps]	Transfer Interval
Voltage Control	99.999%	100 - 500 ms	> 100	10 s – 1 min
Inertia Estimation	99.99%	100 ms	20 - 2000	1 – 100 ms
Frequency Regulation Metering	99.99999%	NA	> 12	100 ms
VPP Coordinated Frequency Control	99.9999%	< 50 ms	> 6	100 ms
VPP Automatic Generation Control	99.99%	NA	> 3	1 s
VPP Optimisation	99.99%	< 5000 ms	> 1	15 min
Advanced Flexibility Trading	99.99%	< 50 ms	> 100	1 ms - 15 s
edgePMU	99.999%	< 20 ms	> 5000	≤ 1 ms

3.3 5G Device Management API requirements of edgeFLEX services and enablers

Ericsson made a novel 5G Device Management API proof of concept prototype implementation developed prior to this project available to edgeFLEX to enable this novel API to be tested and its functionality adapted to the needs of edgeFLEX services. Our goals in edgeFLEX related to the 5G Device Management API were:

- To investigate the API related requirements of the edgeFLEX services and enablers to define how the 5G Device Management API can be used,
- To define which of the 5G Device Management API features address the requirements of these edgeFLEX services and enablers, and
- To evaluate the usefulness of this API for the edgeFLEX services and enablers, power system operators and VPP operators.

The 5G Device Management API related requirements of edgeFLEX services and enablers were defined. For each requirement, we investigated and defined the necessary operations to be performed and described the potential solution descriptions, including the use of the 5G Device Management API features as well as the advantages of using the API to address the relevant requirement. As a result, the mapping of the edgeFLEX service requirements with the API features are given below:

Table 3-2: The 5G Device Management API Features and the API related requirements of edgeFLEX services and enablers

Requirements \ 5G Device Management API Features	Remote orchestration of the group of devices	Automatic software deployment of edgePMUs	Identification of the VPP assets	Direct communications between devices and applications
Device Provisioning and Onboarding	✓	✓	✓	✓
Device Connectivity Management	-	✓	-	✓
Device Connectivity Monitoring	-	✓	-	✓
Device Group Management	✓	✓	-	-

The features of the 5G Device Management API listed in Table 3-2 are considered in edgeFLEX, as these features are the most relevant ones to address the API related requirements of edgeFLEX services and enablers. The details of these requirements listed in the table are given in Annex A.2. The details of these API features were already described in detail in D4.1 [6] and D4.3 [8]. However, for simplicity, a summary table is included below:

Table 3-3: Overview of the 5G Device Management API Features

API Feature 1	Device Provisioning and Onboarding
Description	One of the features that the 5G Device Management API has is called “device provisioning and onboarding”. This feature enables 5G-capable devices to be accepted by the 5G network by provisioning the relevant UE information (e.g., subscription identification numbers) to the 5G network. Then, devices are onboarded to the 5G network and have communication links created for them with default Quality-of-Service (QoS) parameters. Thus, devices can communicate with other devices or services and send their data.
API Feature 2	Device Connectivity Management
Description	When a device is onboarded to the 5G network, it gets a communication link with default QoS parameters, which means parameters are not optimized for a specific use case. However, in case a use case requires e.g., high priority for its traffic or high bandwidth, then the “device connectivity management” feature of the API can be used to change the values of connectivity parameters of a device to the desired level. Thus, default QoS parameters of a communication link are optimized for the requirements of a specific use case.
API Feature 3	Device Connectivity Monitoring
Description	When a device is onboarded to the 5G network, it gets a default communication link as mentioned above. In case the quality of this link is required to be monitored, the “device connectivity monitoring” feature of the API can be used. Some examples of these monitoring data are the values

	of QoS parameters of a communication link, the status of the certificates, current reference signals received power or current packet loss etc.
API Feature 4	Device Group Management
Description	When more than one device is available and onboarded to the 5G network, some of the devices, e.g., serving the same purpose, would need to be grouped. Grouping the devices would help a user to manage the data transfer better and monitoring of a group of devices compared to monitoring of devices individually would be easier. For this purpose, the “device group management” feature of the API can be used to create, modify, and remove device groups. As an example, a device group can be created, in case devices transmit the same type of data, serve the same purposes, or have the same QoS characteristics.

3.4 The impact of the physical locations of devices on the deployment of 5G for future commercial rollouts

Geographical position of devices that will be connected to the power system through 5G network is important for the planning of the 5G network installations, e.g., for optimal placement of the 5G antenna and radio signal distribution planning. Furthermore, conditions for physical installations of devices plays important role, e.g., if a device is in a cellar of the building or in a metal container where a radio signal is harder to penetrate through. Physical conditions for deployments of the devices in two most advanced project field trials were investigated. The results of the investigation are presented in Table 3-4 and in Table 3-5.

Table 3-4: Physical conditions of device deployments in slow and fast dynamics in Wunsiedel Germany relevant for 5G installation

	Current deployment in the field trial (August 2022)	Deployment in the field trial aimed in the project	Potential deployment in a future commercial power grid
Power grid service	Voltage control service	Voltage control service	Voltage control service
Number of deployed devices	3 edgePMUs in three different locations 5 FEMS devices in five buildings above ground	2 edgePMUs in two secondary substations 5 FEMS in five buildings above ground	Options: 1) Maximal number of devices deployed: 100's edgePMUs in Wunsiedel (1 edgePMU per substation) 1000's in Wunsiedel (1 FEMS per house) 2) Optimal number of devices that would be installed realistically: 10's edgePMUs in Wunsiedel (1 edgePMU per each ~third substation) 100's in Wunsiedel (1

			FEMS on each ~fifth house)
Geographical area needed to be covered with the radio signal to reach all devices	Devices are installed on three locations few kilometres away from each other. Each location is ~100's m2 big. It might be enough to cover only one location.	Devices are installed on three locations few kilometres away from each other. Each location is ~100's m2 big. It might be enough to cover only one location.	Area of the city Wunsiedel, ~50 km2
Where the device is installed	edgePMUs are installed in the substation (typically container). FEMS is installed in the building above ground.	edgePMUs are installed in the substation (typically container). Feeders are under ground. FEMS is installed in the building above ground.	edgePMUs could be installed either in the substation (typically container) or on the feeder. Feeders are under ground. FEMS is installed in the building above ground.

Table 3-5: Physical conditions of device deployments in fast dynamics in Italy relevant for 5G installation

	Current deployment in the field trial (August 2022)	Deployment in the field trial aimed in the project	Potential deployment in a future commercial power grid
Power grid service	Voltage control service	Voltage control service	Voltage control service
Number of deployed devices	5 edgePMUs in the container	5 edgePMUs in the container 5 commercial PMUs in the container	If A2A would deploy the voltage control service as in the field trial, then all devices might be deployed in one container. The number of the devices is not relevant anymore because one radio station could cover them all.
Geographical area needed to be covered with the radio signal to reach all devices	1 factory building (~ 100 m2)	1 factory building (~ 100 m2)	If A2A would deploy the voltage control service as in the field trial, then one radio station would be enough to connect all devices used in the service.
Where the device is installed	Devices are installed in the container in a field.	Devices are installed in the container in a field.	If A2A would deploy the voltage control service as in the field trial, then devices would be installed in one place (container).

3.5 Conclusion of the section

Our studies of defining 5G ICT requirements of services and enablers studied and developed in edgeFLEX showed that they can already be supported by 5G networks, and their communications requirements can already be fulfilled, as 5G can address more stringent requirements of services compared to the former mobile networks. For example, edgeFLEX services would benefit from the high levels of communication service availability, reliability and security that 5G networks can offer compared to the other networks such as 3G or 4G. We have identified with the project partners that some of the services require high levels of communications service availability to operate and those levels of availability could only be achieved with the use of 5G networks. The latency requirements of some of the services, such as voltage control or VPP optimisation services, can be fulfilled with the use of 3G or 4G networks. However, the latency requirement of the edgePMU which is less than 20 ms can be only met by 5G, but not by 4G networks.

To provide full support for the energy services that can be supported by 4G network and at the same time the energy services that cannot be currently or will not be able to be supported by 4G in the future, 5G networks need to be available at the location and this is not yet the case for all of the edgeFLEX field trial locations. Lastly, we identified that the 5G requirements related to the service bit rate and the transfer interval of edgeFLEX services are not challenging from the 5G perspective, apart from the use cases with edgePMU. However, the communication requirements of almost all edgeFLEX services will evolve in time which will bring more stringent requirements to communication system that can only be supported by 5G.

In addition to the 5G ICT requirements, we have also investigated the requirements of the edgeFLEX services and enablers on the 5G device management API. These investigations were undertaken to define how the 5G Device Management API would be used by power system and VPP operators. Furthermore, after defining the requirements of edgeFLEX services and enablers related to the API, we identified which of the API features would address these requirements. We described these API features in detail and accordingly, we created a mapping between these features and the requirements of edgeFLEX services and enablers that would benefit from the 5G Device Management API. As a result, we have validated the usefulness of the 5G Device Management API for the energy services and showed how to optimize the daily operations for power system operators and VPP operators with the use of the API.

4. 5G solutions supporting edgeFLEX services and enablers and their commercial deployment aspects

This section describes relevant 5G ICT solutions supporting the communications requirements of the services and enablers developed in the edgeFLEX project and the potential timescales and constraints relevant for the deployment of the edgeFLEX services and enablers in commercial scale deployments supported by 5G networks.

The edgeFLEX services described earlier require a range of new ICT solutions to support their functionality. 4G or 5G solutions can be chosen as an alternative to current Wi-Fi solutions, and legacy systems solutions such as those based on Land Mobile Radio (LMR) and ubiquitous RF-mesh-based communications networks.

4.1 5G solutions supporting edgeFLEX services and enablers

4.1.1 Campus Area Private 5G Networks

Critical infrastructure owners are increasing their use of local area private 5G networks, also known as Non-Public or Campus Networks, in restricted areas [12]. Hence, they can provide 4G and 5G services to fulfil the communications requirements of local businesses, for example in the campus areas of power generation plants. Such networks are generally privately owned networks, which are sometimes operated by external service providers on behalf of their owners. Local area private networks offer complete control of the use of communication network. The owners of these networks can configure the access to the network, the use of its resources and its quality of service and security parameters, as required by the energy services to be supported.

A local area private 5G network could be deployed by a power system operator to provide part, or all the connectivity required by the energy services described earlier, if they have acquired access to suitable radio frequency spectrum. Local area private 5G networks offer the advantage that the network owner, a power system or a VPP operator, has complete control of the communications network in terms of investment priorities, security, configuration, access, roadmap, evolution, and life cycle management.

4.1.2 Hybrid 5G Networks

Combining a public 5G and private 5G network into a Hybrid 5G Network for energy services can also offer a flexible solution supporting the communication requirements of energy services. Hybrid networks can facilitate the control of critical infrastructure assets using a geographically restricted, private dedicated network complemented using public mobile network operator networks for controlling less important, dispersed, critical infrastructure assets.

4.1.3 Mission Critical Wireless Networks

Mobile networks, such as 4G and 5G, offer cost-effective solutions providing secure and reliable communications to fulfil the requirements of energy services. Although public mobile networks, operated and owned by public mobile network operators, can often be used to provide connectivity to large numbers of energy devices distributed over wide geographical areas, power infrastructure owners are often keen to deploy networks complying with their more stringent critical infrastructure communication requirements. Communications networks which have the capability to meet such stringent critical infrastructure communication requirements are often described as Mission Critical Networks.

Specialised versions of standard 5G solutions are available which are tailored to support the specific needs of mission critical applications. Mission critical networks based on the 3GPP 4G and 5G standards are designed to comply with mission critical network requirements regarding their reliability, availability, quality of service and security and such networks can be configured to offer a full range of features supporting reliable and secure power grid operations [13].

4.1.4 Mobile networks solutions for massive IoT- communications

When latency and high bandwidth are not critical requirements, other mobile network technologies than Mission Critical 4G or 5G, can be used to support energy services. For example, extended coverage GSM IoT (EC-GSM-IoT) networks, LTE for Machines (LTE-M) networks or Narrowband IoT (NB-IoT) networks can be considered as alternative solutions.

4.1.5 5G Edge Cloud solutions

To reduce the latency of communications in wide area mobile networks, edge cloud capabilities enabled by 4G and 5G are often included in the architecture of communications solutions. 5G offers edge cloud capabilities integrated into the network infrastructure and the 5G infrastructure vendors offer such solutions. The 5G edge cloud is constantly synchronised with the 5G central cloud.

Solutions can also be developed using servers not integrated into the LTE or 5G infrastructure. These servers can be located physically close to base stations to provide edge cloud capabilities.

Besides the reduction in latency, edge cloud is also beneficial for hosting services locally, close to the power assets. In case the edge cloud is placed on power system or VPP operator's premises, it is possible to provide local communications and higher security. For some of the edgeFLEX services and enablers, it is required to use edge cloud to process the data locally on the premises such as the voltage control service, the VPP optimisation service, and the advanced energy flexibility trading service.

4.1.6 Central Cloud

Unlike edge cloud, central cloud is the computation and storage asset that is not deployed so close to the power assets but deployed farther away. Central cloud can be either operated by communication service providers or it can be managed by other service providers such as hyperscale service providers.

For some of the edgeFLEX services and enablers, central cloud is needed to process the data. These services include inertia estimation, frequency regulation metering, VPP coordinated frequency control and VPP automatic generation control. In addition, central cloud can be used to host the visualisation tools developed as components of the edgeFLEX platform.

4.1.7 Organised fail-safe mode of operation for cloud-based services

The failure of the edge cloud synchronisation with the central cloud was investigated as a use case. When the failure happens in public mobile networks, an organised fail-safe mode of operation for cloud-based services and their associated databases should be ensured. The fail-safe mode of operation can ensure communication service continuity that edgeFLEX services will benefit of. Such fail-safe mode of operations in case of failed synchronisation in public mobile networks has already been incorporated into Ericsson products in the past two years. The mechanisms implemented in public mobile networks supporting the fail-safe operations are described in detail below.

There are many options of recovery after the failure has happened that can be performed by mobile networks. Some recoveries can be performed in an automatic manner, and some can request manual actions. To enable recovery of the network, network management entities aka. controllers need to keep networking configuration information. The controller is a network management entity that manages a single instance of the product such as edge cloud hardware or Kubernetes cluster. E.g., the controller in the edge cloud stores networking configuration information such as VLAN definitions, security setting or cabling.

After a communication failure happened and the communication is re-established, a health check is performed to see if the system is operating. If the system is operating, then the consistency of a network node configuration is checked by the controller. If there is an inconsistency, then it is

resolved either automatically or manually. The basic idea is to restore a network node configuration as wanted from the controller itself. Synchronisation between network nodes deployed in distributed manner needs to be considered during the network design.

We can illustrate the fail-safe mode of operations with an example of a loss of synchronisation between central and edge cloud. Let's assume that the communication between the central and the edge cloud failed because of a power outage. After the power outage, 9 servers out of 10 in total have recovered. In this scenario, the central cloud needs to know the new network topology. Accordingly, the topology information needs to be rebuilt in the central cloud so that communication services can continue to be operational.

4.1.8 Prototype 5G Device Management API increases ease of use of 5G

As the use of Renewable Energy Sources (RES) is increasing and the stability of power grids becomes more challenging, the role of remote control and remote monitoring of the connectivity of the power assets becomes more important. Mobile technology, especially 5G, is currently more visible and interesting to power sector actors thanks to the developments and enhancements in 5G networks to make it more transparent and easier-to-use. Power sector actors are now purchasing 5G as the communication technology for their power assets.

However, as developers from power sector are often not deeply involved in mobile communication technologies, it can be challenging for them to integrate their existing power systems, devices, and infrastructure with a 5G network. The provision of a 5G capabilities exposure API with an easy-to-use GUI would help developers to reduce the time needed for such integration and help them visualise the edgeFLEX services and the performance of the 5G network. An already available prototype version of such an API has been investigated by edgeFLEX and its functionality has been further developed to support demonstrations of the support it can provide to edgeFLEX services.

Power sector actors can use the 5G Device Management API and the new GUI to establish new connections, create device groups, monitor the quality of the communication link to a device or change the parameters of a communication link in order to increase the quality of service.

4.1.9 Ultra-Reliable Low Latency Communications (URLLC) in 5G networks

The Ultra-Reliable Low Latency Communications (URLLC) feature of the 5G network provides low latency and ultra-high reliability for services placing stringent requirements on communications. URLLC functionality has been standardised by 3GPP [14]. These services are referred to also as mission-critical services requiring higher than normal levels of reliability and security. Examples of services in edgeFLEX include the VPP coordinated frequency control service and the edgePMU, both of which require low latency.

When URLLC capabilities are available in 5G products, 5G is expected to achieve an average latency over the 5G radio link of 0.5 ms and successfully transmitting a 32-byte message over the 5G radio link within 1 ms with a reliability of $1-10^{-5}$ [15]. Thanks to the time slots in the radio transmission being as short as 0.125 ms and the possibility to prioritize data without waiting for slot boundaries, URLLC can provide lower latency. High reliability can be provided by extra-robust transmission modes and multi-antenna transmission for extra redundancy and packet duplication [16].

4.1.10 5G Network Slicing

The new network slicing service of 5G networks can provide solutions for use cases in which for example, a power system operator needs to have a certain quality of service and security, or a control service being used by a VPP operator needs to have high availability of the communication service at least for a defined period of time. The network slicing technique allows the definition of multiple logical networks (so-called slices) within the same physical infrastructure. The resources can be assigned exclusively to one slice or spread over several slices [17].

A network slice is established to ensure a specific behaviour by the network. This behaviour can be related to security, data flow separation, quality of service, reliability, separate billing, and other factors. A network slice can support one or more services and can be used to set up a virtual carrier network that corresponds to specific customer-specific service characteristics. Thus, network slicing allows power system operators and VPP operators to set their own priorities for the communication resources in the network slices which they have reserved. Network slicing can be used for different purposes: to provide a complete virtual private network, to provide a copy of a public network for testing a new service, or to provide a special network functionality for a specific service.

4.1.11 Using lightweight security protocols for end-to-end security solutions for low-cost devices

Mostly, the power system operators and VPP operators need high security for their data transmissions and operations. Therefore, they implement various security measures on their premises. Besides the physical protection, the developers also implement security protocols on the devices and services. However, for some low-cost measurement devices with limited computational power, security protocols could create overload on their processing power. The data acquisition devices of edgePMU are also examples of such devices. If high security could be achieved by other means, then the computational load on these devices could be decreased. We describe below some of these solutions investigated in the edgeFLEX project which aim to provide end-to-end security while keeping the load on devices low.

To transmit data from low-cost devices to the applications hosted on a server, virtual private networks (VPNs) are generally used. For data transmission from the device to the application, application layer protocols ensuring high security in data transfer are used. One of the security protocols commonly used in this purpose is “Transport Layer Security (TLS)”. However, TLS and other regular protocols are often not suitable for devices with limited capacity, as they are not optimized to be used on those devices and they can cause overload for the device. On the other hand, protocols exist which have been tailored for Internet-of-Things (IoT) use cases. The Constrained Application Protocol (CoAP) [18] is an example of such a protocol. CoAP is a protocol which was designed to support constrained devices, such as sensors and IoT devices, performing very lightweight operations. Another protocol that was also designed for lightweight operations and built on top of CoAP is called “Object Security for Constrained RESTful Environments (OSCORE)” [18]. OSCORE is a protocol that support end-to-end encryption with a lightweight key management. It provides low overhead by protecting only the relevant information coming from the application layer messages. Thus, it provides smaller overhead on the lower layer messages. The edgeFLEX services would also benefit from using OSCORE protocol.

4.1.12 eSIM solutions

As the devices from power system operators or VPP operators are placed mostly outdoors, it could be challenging to use traditional, plastic SIM cards to deploy in their devices. Besides, if the area has high humidity and high temperature, it is likely that the health of these SIM cards would be lower and there is a need to more frequently change the cards inserted to the devices in the field. However, there is a solution available to eliminate the dependency on using traditional cards, which is called embedded Subscriber Identification Module (eSIM) [19]. eSIM, or in other words embedded universal integrated circuit card (eUICC), is a type of identification module that allows devices to directly start communicating once user selects a subscription plan from a mobile operator and provision the pre-defined identification details of the device. eSIM eliminates the need to go to a shop and buy a traditional SIM card and insert it to a device, as it is mounted on the circuit board of the mobile device [20]. It provides flexibility and integrity compared to the traditional SIM card, although their costs are similar. In this way, power system or VPP operators could activate their devices remotely, onboard them more quickly to the 5G network, and they can have more flexibility to change the mobile operator or the subscription profile easily.

4.1.13 Summary

Relationship between the 5G solutions and the edgeFLEX services is indicated in Table 4-1. The relationship is provided in the context of the service deployment in commercial rollouts.

All the 5G solutions described in this section are beneficial for edgeFLEX services. Of the 5G solutions listed in the table, private networks, edge cloud, 5G Device Management API and URLLC were used and tested in a laboratory environment and test results are reported in D5.5.

Table 4-1: 5G solutions for edgeFLEX services and enablers

Service/ enabler 5G solution	Volta ge Contr ol	Inertia Estimati on	Frequen cy Regulati on Metering	VPP Coordinat ed Frequency Control	VPP Automat ed Generati on Control	VPP Optimi sation	Advanced Flexibility Trading	edge PMU
Private Networks	✓	✓	✓	✓	✓	✓	✓	✓
Hybrid Networks	✓	✓	✓	✓	✓	✓	✓	✓
Mission Critical Networks	✓	-	-	✓	✓	✓	✓	✓
Mobile Networks for Massive IoT Communications	✓	✓	✓	✓	✓	✓	✓	-
Edge Cloud	✓	-	-	✓	-	✓	✓	✓
Central Cloud	✓	✓	✓	✓	✓	✓	✓	-
Organised fail-safe mode of operation for cloud-based services	✓	-	✓	✓	✓	✓	✓	✓
5G Device Management API	✓	✓	✓	✓	✓	✓	✓	✓
URLLC	-	-	-	✓	-	-	-	✓
Network Slicing	✓	✓	✓	✓	✓	✓	✓	✓
eSIM	✓	✓	✓	✓	✓	✓	✓	✓

4.2 Timescales and conditions for deployments of edgeFLEX services in commercial rollouts with 5G

In this section, the timescales and conditions for deployments of edgeFLEX services and enablers are presented. The deployment timescale is divided into short-term (in 3 to 5 years), medium-term (between 3 and 10 years) and long-term (in 10 years) deployment. In addition, the conditions for deployments of the services in commercial rollouts which are likely to occur are summarized.

4.2.1 edgeFLEX Voltage Control service

The management of VPP assets by DSO operators that deploy voltage control services is not allowed today. Accordingly, regulatory change is needed in this context. edgeFLEX has proposed regulatory changes and is discussing them with national regulators and promoting such change in public events. Furthermore, interactions between the voltage control service and flexibility energy trading services are not possible today. Accordingly, regulatory change is needed to support such interactions. It is a precondition for deployments of the service in commercial networks with 5G.

The edgeFLEX voltage control service will be able to control DSO and VPP assets as well as to interact with local flexibility markets. In early service deployments, limited number of assets will be controlled by the service. It is expected that number of controlled assets will increase progressively with time. Additionally, the service requirements are expected to be more demanding in future leading to improved quality of voltage control services. In early rollouts of voltage control services, 4G networks will generally be sufficient to support the service. When the service requirements become more demanding in future, the enhanced capabilities of 5G networks will be needed.

Local energy communities will become new players in the energy system once the legal conditions for their establishment have been finalised and will be able to deploy the edgeFLEX voltage control service. The edgeFLEX field trial in Wunsiedel demonstrates the interest of local communities to become part of or as a whole become Energy Communities as active participants in the energy system. The Energy Communities will provide additional operational flexibility to the power grid through intensive interactions between the voltage control service and the local flexibility market leading to a more locally balanced grid, reduced energy losses in transmission and a stable energy supply with fewer service interruptions. The energy communities will bring massive number of devices that will need to communicate with the service. Therefore, the role of 5G will be extremely important enabling connecting of devices with the service.

4.2.2 edgeFLEX Inertia Estimation service

The edgeFLEX Inertia Estimation service belongs to the category of frequency monitoring services. Because of the high penetration of renewable energy sources, the absence of inertia in power systems is the issue that some power system operators experience already and work on its mitigation. The problem of inertia estimation will grow in the coming years.

The edgeFLEX inertia estimation service can be offered to TSOs today in current power networks because regulatory change is not needed before the service can be deployed. In Sweden, a tool for inertia estimation is already available and is being used. In the UK, a tool for inertia estimation and inertia forecasting is also available. Inertia estimation could be a useful tool for DSOs in the future (2030+), if they have virtual inertia provisioned in their system.

TSO use fibre communications for their energy balancing services today. As DSOs and Energy Communities implement such functionality, the advantage of being able to deploy wireless communications links at low cost and quickly to connect new assets to frequency regulation services will mean that wireless communications will increasingly be used to provide communications for such services.

4.2.3 edgeFLEX Frequency Regulation Metering service

The edgeFLEX Frequency Regulation Metering service belongs to the category of monitoring frequency services and similar market development to that of the edgeFLEX Inertia Estimation service is expected for it. This service targets the TSO market today because TSOs are responsible for frequency system stability and for the balancing services.

The edgeFLEX Frequency Regulation Metering service can be helpful for DSOs in the future (2030+) if new roles are enabled for DSOs. Such roles for DSOs could be in the provision of frequency control or network balancing services to the grid. It could be used to monitor non-synchronous generators available in DSOs network and also for provisioning of frequency support. The service does not directly interact with the energy markets, but TSOs can use the information provided by the service, e.g., for balancing of energy or to reward the resource.

In TSOs systems, fibre communications will generally be used to support the edgeFLEX Frequency Regulation Metering service. In future scenarios, DSOs will use both fibre and wireless communications to avail of the advantage wireless communications offers of low cost and quick deployment of communications links to connect new assets to the service.

4.2.4 edgeFLEX VPP coordinated frequency control service

The edgeFLEX VPP coordinated frequency control service is intended for VPP use. The commercial rollout of the service is foreseen in couple of years (2025+), because now VPPs do not provide fast frequency regulation services (FFR). But this situation is expected to change in a couple of years when we expect to see regulatory change being implemented. This service has stringent communication requirements which will benefit from the of 5G (low latency and high reliability). This service requires the support of tailored systems supporting mission critical communications to stabilise the power grid within very short time frames.

4.2.5 edgeFLEX VPP Automated Generation Control service

VPPs are the target market for the edgeFLEX VPP Automated Generation Control service. The rollout of the service is foreseen in a couple of years (2025+) if new regulations enabling VPPs to provide fast frequency regulations (FFR) have been implemented. edgeFLEX is promoting such regulatory change. 5G networks being deployed nowadays can already fulfill service requirements.

4.2.6 edgeFLEX VPP Optimisation service

Today, advanced algorithms for optimisation of the financial results of VPP asset owners exist. However, the edgeFLEX VPP Optimisation service improves on these existing solutions. The goal of the service is to reduce the costs of VPP owners through, for example, charging of batteries when the wind is blowing, when the energy price is lower, or when the demand for power generated by wind turbines is lower than usual. Currently, energy distribution and dispatch are planned in intervals of 1 hour. The edgeFLEX VPP optimisation solution will shorten this interval to 15 minutes improving the financial outcome of the VPP owner. Generally, the edgeFLEX service enables optimised trading on the power intra-day market. VPP asset owners can be expected to implement such a new technique only if it decreases their costs by at least 1%.

Currently the edgeFLEX VPP Optimisation service is running in the central cloud (Amazon). The aim of our work is to push the execution of the algorithms to the edge of the network to reduce the risks of loss of revenue associated with having a single, central point of failure (the central server). In an advanced deployment scenario, the service logic will be deployed in a distributed architecture, in which the service instances will communicate among themselves. A high processing power, processing up to thousands of iterations, is foreseen to crunch the high volume of data produced. In such a scenario with a high processing power utilised over wide or campus geographical areas in a distributed architecture, maintaining low communications link latency will be a critical factor in the optimisation of the service.

The service can be deployed in the commercial power network communicating with VPP facilities in 3-5 years. In long term (10 years), one cloud per facility (e.g., per wind park) is expected to be used. By then, VPP facilities will become smaller and smaller as more small assets are added to the VPP network for management. This is expected to happen as consumers join Energy Communities, which enable small assets to participate in energy markets. In the future, an asset could be as small as a battery at home or a refrigerator in a restaurant.

The edgeFLEX partner Alpiq, which operates VPPs and wind parks as well as extensive power distribution networks, foresees a big shift in the scale of the energy assets they will manage. They anticipate a transition from the current scenario of managing large energy assets and facilities, such as a complete wind farm, to a scenario in which they manage and optimise a high number of small or very small assets.

Energy market actors will not be impacted by the edgeFLEX VPP optimisation service. However, the service will influence the energy markets indirectly by improving the efficiency of VPP operators, i.e., by increasing their potential to generate revenue.

No impact on network codes is foreseen for the edgeFLEX VPP optimisation service.

4.2.7 edgeFLEX Advanced Energy Flexibility Aggregation and Trading Service

The edgeFLEX Advanced Energy Flexibility Aggregation and Trading service comprises two sub-use cases:

- The Automatic Flexibility Aggregation and
- The Reactive Power Trading and Management.

The sub-use case of Automatic Flexibility Aggregation at the DSO level does not yet exist, and it is a new technique. The service is going one step further than the edgeFLEX Automatic Flexibility Aggregation to offer Reactive Power Trading and Management.

In the short term, the sub-use case of Reactive Power Trading and Management can be used where the trading is completed between 1 hour and 1 minute before the predicted event (problem) occurs. Preferably, the trading should be completed between 15 minutes to 1 minute before the predicted event occurs in order to get close to real-time reactions.

In the long-term solution, the sub-use case of Reactive Power Trading and Management can be used, where the flexibility management is started 1 minute or less before the event (problem) occurs and continues also 1 minute or less after the event occurs. This time, the action is based on the real-time data, instead of a prediction. This enables real-time flexibility management instead of flexibility trading, but then management requires communication within the timeframe of milliseconds.

In the sub-use case of Automatic Flexibility Aggregation, the Frequency Control service will not use the flexibility offers, whereas the Voltage Control service has a potential to combine grid management with flexibility offerings. In the sub-use case of Reactive Power Trading and Management, both the Voltage Control and the Frequency Control service should be considered.

4.2.8 edgeFLEX edgePMU

The edgeFLEX edgePMU device prototype version is developed and deployed in the project field trials. The device can and is being deployed in commercial networks now. The user of the edgePMU can be DSOs, TSOs and VPP operators. If the user wants to use mobile network connectivity, then only 5G has the communication characteristics needed to support the edgePMU by providing the edgePMU with edge cloud capabilities and the needed high-performance communications links.

Once deployed in the edge cloud, the edgePMU software can be remotely updated by the user. The function of the edgePMU can be changed remotely. This reduces the need to send the staff to the field reducing costs for SOs.

4.3 Global 5G standardisation contributions made by edgeFLEX

In the project, edgeFLEX use cases potentially benefitting from 5G systems as well as use cases placing stringent requirements on 5G systems were analysed. As a result of the analysis, the edgePMU has been identified as the use case that sets the most stringent requirements towards the 5G system. The edgePMU use case was contributed to and accepted by the 3GPP SA1 standards group responsible for the global standardisation of 5G systems. The use case “Edge cloud driven data acquisition (edgePMU)” is published in the 3GPP standards technical report 22.867 [9]. The technical report describes the edgePMU data flow and the 5G requirements of the use cases using the edgePMU.

The second use case successfully contributed to the 3GPP SA1 standard group in edgeFLEX project was the use case of ensuring uninterrupted Machine-Type Communication (MTC) service availability during emergencies. This use case was defined and described in the eSafeNet project [21] and is related to the organised fail-safe mode of operation for cloud-based services as described in Section 4.1. We further investigated, created information flows and defined 5G requirements of this use case in the edgeFLEX project. The use case was accepted by the 3GPP SA1 standards group. The published 3GPP technical report 22.867 [9] describes the use case flow and the 5G requirements in detail.

After contributing the use cases to 3GPP standards, the edgeFLEX project was involved in the work of 3GPP SA1 group where the 5G requirements of the contributed use cases were discussed with the goal of defining normative service requirements for 5G systems. As an output of this activity, the use case of ensuring uninterrupted MTC service availability during emergencies and its 5G requirements are included in 3GPP Stage 1 normative service requirements for 5G systems described in the 3GPP standards document 22.104 [11]. In Stage 2 and Stage 3, the Stage 1 normative service requirements will be studied in other 3GPP standards groups (SA2 to SA6) to incorporate them into the overall architecture and service capabilities of 5G networks.

4.4 Conclusion of the section

Our studies on suitable 5G solutions for edgeFLEX services and enablers showed that edgeFLEX services and enablers can be supported by 5G technology. For example, a system operator can use a local area private 5G network to host an edgeFLEX service on an edge cloud and achieve low latency. Our studies of cloud solutions supporting both edgeFLEX and various other use cases showed that edge cloud not only increases the resilience of the power network and allows hosting services locally in a power network, but also reduces the communications latency between devices and services. In addition, for edgeFLEX services and enablers requiring high priority or low latency, the advanced 5G services, such as network slicing and the URLLC service, can be used to reduce the over-the-air latency to 1 ms using URLLC or to ensure communications service availability for a particular service by using network slicing. Furthermore, the possibility of using lighter-weight protocols can enable increased security while maintaining low overloads on devices with limited processing power, such as edgePMU devices. Lastly, existing solutions, such as eSIM, can allow power system operators to start using 5G technology faster, as the eSIM solution can support the various weather and humidity conditions to be expected in the areas in which the power assets are located. The eSIM solutions can be used by power system operators as an alternative to or together with the prototype 5G Device Management API for the onboarding of their field devices to 5G networks.

Apart from identifying the 5G solutions for the edgeFLEX services and enablers, we also defined the timescales and conditions for the deployment of the edgeFLEX services and enablers in commercial rollouts using 5G networks.

As the 5G requirements of use cases defined for the edgeFLEX edgePMU are stringent, we investigated the potential contribution of these new 5G requirements to the relevant standardisation groups so that 5G and future technologies will be able to support new use cases and concepts. Furthermore, we continued our investigations on providing uninterrupted communications should power blackouts occur, started during the eSafeNet project. We also investigated the potential to contribute this new use case to the standardisation bodies. As a result, we contributed the edgeFLEX edgePMU and the use case of ensuring uninterrupted MTC service availability with new requirements on the 5G networks to the 3GPP SA1 standardisation

group. Our contributions were accepted by 3GPP and published as an enhancement to the previously existing 5G standards.

5. The GUI developed for the 5G Device Management API

In this section, the focus will be on describing the work we undertook to develop a GUI for the 5G Device Management API proof-of-concept prototype. The main goal for the GUI design and development is to be compatible with the key features of the 5G Device Management API which currently include:

- Device Provisioning and Onboarding,
- Device Connectivity Management,
- Device Connectivity Monitoring, and
- Device Group Management.

The purpose of developing this GUI was to:

- Allow any power sector user (including users from power system operators) to use the 5G Device Management API more easily for their operations without requiring the help of a 5G expert,
- Illustrate the features of the 5G Device Management API addressing the requirements of the edgeFLEX services and enablers, and
- Visualize the procedures of the 5G Device Management API needed for certain operations.

EDD performed integration and testing activities as part of our investigations and definition of new use cases and potential business cases for future commercial deployments of edgeFLEX services with 5G and the 5G Device Management API. The edgePMU software package was integrated into the 5G laboratory network infrastructure in which the 5G Device Management API was available as a proof-of-concept implementation.

The required communication architecture for the edgePMU was provided via the 5G Device Management API using the GUI developed specifically for this edgeFLEX demonstration. This work was performed to show that the components of the edgeFLEX platform (of which the edgePMU forms a component) can be integrated into the 5G Device Management API as well as to demonstrate the key features of the API. In the following sections, we show that the 5G devices and applications hosting the edgePMU software are connected end-to-end to each other using the 5G Device Management API.

The key benefits of the 5G Device Management API for power system operators and VPP operators as power providers are that it:

- Enables power providers to use and benefit from 5G without a need for a in depth 5G communications knowledge,
- Enables power providers to connect and group their field devices,
- Enables monitoring of the status of the communication to their field devices,
- Exposes the 5G network capabilities to power providers enabling them to simply implement their energy use cases and services.

Key results of this work are that:

- The API can now be visualized and demonstrated, using the newly developed GUI, to onboard and group devices, and to monitor device connectivity,
- The secure bi-directional data exchange between field devices and applications hosted on an edge cloud can be visualized and demonstrated for edgeFLEX services,
- The monitoring of the status of the communication to field devices can be visualized and demonstrated for edgeFLEX services, and

- The proof of isolation between two different device groups can be visualized and demonstrated for edgeFLEX services.

5.1 The development and functionality testing of the 5G Device Management API GUI

The 5G Device Management API is a powerful concept enabling increased ease of use of 5G to the developers in industrial domains. It speeds up the integration of energy services with 5G networks and enables industrial users to create and launch new energy services in the market. Beneficiaries of the 5G Device Management API include power system operators and VPP operators. We target developers and/or workers from the power industry with no deep ICT or 5G knowledge and experience as users of the API. We developed an easy-to-use GUI that is compatible with the Ericsson 5G Device Management API proof-of-concept prototype made available to the project for further development and integration with energy services.

In Section 5.1.1, the development of the GUI for the 5G Device Management API will be described, whereas the functionality testing of the GUI and the steps followed in order for successful API operations are described in Section 5.1.2.

5.1.1 The development of a GUI for the 5G Device Management API

A GUI for the 5G Device Management API was developed and tested. The GUI allows the user to manage and control the network operations through 5G Device Management API and 5G core network. The GUI consists of frontend and backend designs.

The frontend refers to the graphical design of the application, also referred as the client side. The user directly interacts with the frontend of the application. The frontend of an application includes its design, structure, and behavior. Some target users of the 5G Device Management API GUI are authorized users working for power providers. This group also includes people with no deep knowledge of 5G communications. Therefore, the frontend of the application is developed to be simple and user-friendly while providing the full capabilities of the 5G Device Management API. Simplicity and user-friendliness were considered as two important aspects of the development to provide a better and simpler user experience. The graphical design and structure were created using the PyQt5 Python library.

The backend refers to the set of operations performed by the application such as storing and managing data which enables smooth operation of the frontend. The RESTful nature of the 5G Device Management API allows the GUI to interact, enabling the API to send “request” messages to 5G core network and it receives “reply” messages. The requests messages and JSON Python libraries were used for the interaction with 5G Device Management API. The user actions on the frontend result in the backend sending the necessary commands to the API, with the corresponding request bodies in JSON format, and also to the corresponding URL and IP addresses. The received data, regarding any entity created by the API or their related information, is managed and stored by the backend of the GUI.

The features of the API have already been described in previous sections, and they are also shown in the following sections as part of the developed GUI.

A screenshot from the GUI is showing the edgePMU acting as the data acquisition unit in Figure 5-1.

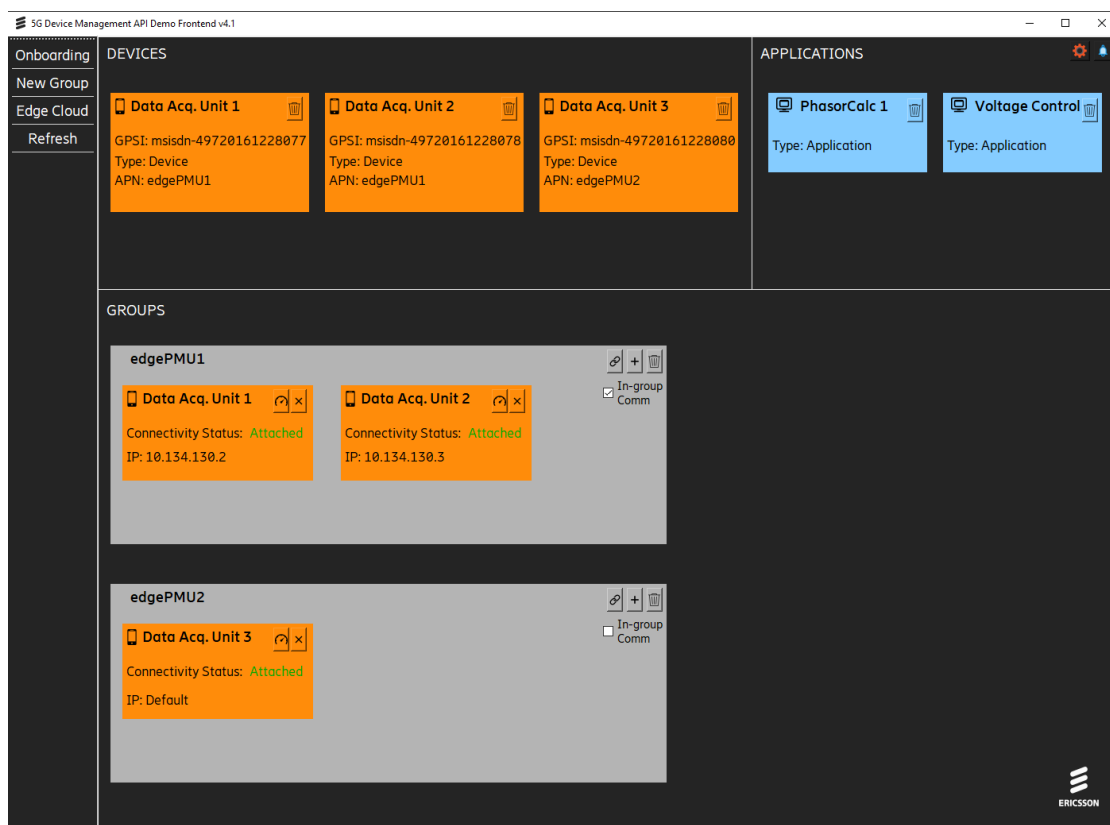


Figure 5-1: The GUI for the 5G Device Management API – proof-of-concept demonstrator

The screenshot in Figure 5-1 is from the latest version (v4.1) of the GUI and was used to demonstrate the edgePMU use case, which includes components of the edgeFLEX platform such as phasor calculation algorithm of edgePMU and the voltage control service.

In the GUI, the devices, applications, and groups are represented as boxes with different colored backgrounds. Each of them will be explained in detail shortly. To begin with, devices are indicated by orange boxes on the left top inside the section with header “DEVICES”, as seen in Figure 5-2.

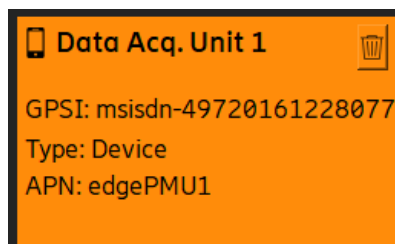


Figure 5-2: Device box from the GUI

Three different information items are displayed within the box for devices:

- GPSI (Generic Public Subscription Identifier),
- Type, and
- APN (Access Point Name).

The GPSI number is a unique subscription identifier reserved in a SIM card used for identifying different users in networks. The 5G Device Management API requires the GPSI number of the device to perform operations regarding the device, and also the same GPSI number is displayed on the GUI, inside each device box. The “type” is an instructive data for the user to understand the type of the entity: either a device or an application. The “APN” indicates the group that device

is currently a member of. In the example above, the device is a member of the device group called “edgePMU1”. If the device is not a member of any group, then the APN is specified as “default”, which is the main group for each device before being a member of any other group. Lastly, the user can remove or delete any device using the button on the top right-hand corner.

The applications on the other hand are displayed by the GUI in boxes with a blue background as shown in Figure 5-3.

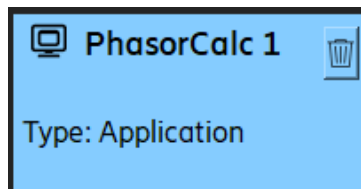


Figure 5-3: Application box from the GUI

Unlike devices, applications are not created by the user via the API, but only displayed by the GUI. The aim is to give a better overall understanding to the user by showing the devices and applications together on the same screen. The applications can be any edgeFLEX service from the edgeFLEX platform that is hosted on the edge cloud. In Figure 5-3, the phasor calculation application, which is part of the edgePMU software, is shown. All the applications are displayed under the header “APPLICATIONS”.

The next type of entity to be displayed on the GUI is device groups, as seen in Figure 5-4.

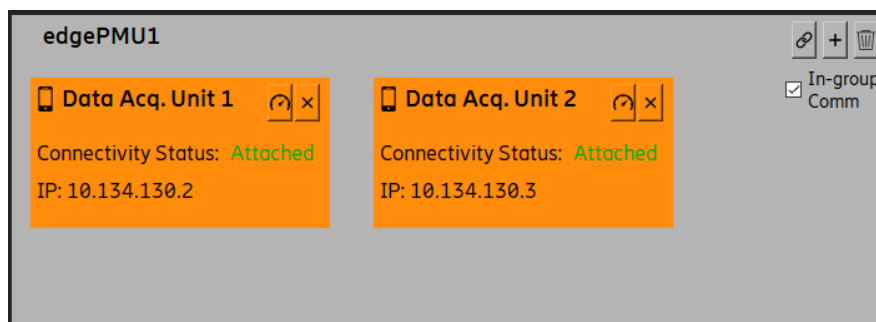


Figure 5-4: Device group box from the GUI

The groups are indicated with the color grey under the section “GROUPS”. Inside each group box, all member devices are displayed. In Figure 5-4, the device group edgePMU1 is displayed. The group has 2 active members: Data Acq. Unit 1 and Data Acq. Unit 2. For each device, “Connectivity status” and “IP” addresses are defined. Connectivity status shows whether the device is attached to the 5G network or not. If the device is actively connected to the network and reachable, then connectivity status appears as “attached”. The IP address indicates the address of the device that was assigned by the 5G network.

The IP address first appears as “default” before any in-group communication is allowed. In Figure 5-4, the “In-group communication” button can be seen on the right-hand side as a checkbox. When checked, the API creates connections between each member of the group, and each member receives an IP address from the network. Therefore, IP addresses are only assigned after the in-group communication is enabled for a device group by the authorized user.

It is possible that the user requests the addition of more members to the group. In such a case, the user can choose any new device to add to the group using the plus icon on the right-hand corner. A new window pops up and lists all existing devices. The user can choose among all devices in the list and the chosen device will be added to the group as a member.

Two buttons inside the orange device boxes are for starting a measurement and removing the membership of the device respectively. The measurement button starts a new measurement for

the chosen device which includes latency and packet loss measurements. These measurements are displayed on a separate window on a circular gauge to give a simpler understanding for the user. An example screenshot for the measurements is given in Figure 5-5.

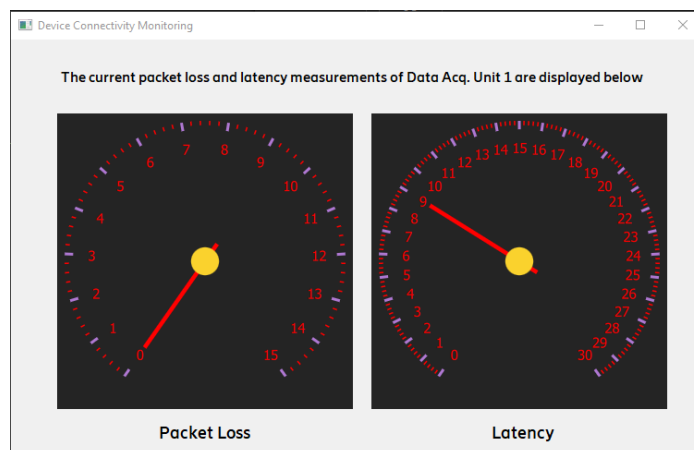


Figure 5-5: Device connectivity monitoring screen from the GUI

5.1.2 The functionality testing of the 5G Device Management API GUI with the edgePMU software

As described earlier, the 5G Device Management API proof-of-concept uses the REST API concept and communicates with relevant 5G core network functions to complete the necessary operation requested by the user. The authorized user can send its requests to the 5G core network through 5G Device Management API using the GUI developed with the edgeFLEX project. Similarly, 5G Device Management API forwards the response from the core network to the GUI for the user to be notified. The laboratory architecture of the 5G Device Management API proof-of-concept, which was used to test the functionality of the GUI and the API itself can be seen below in Figure 5-6.

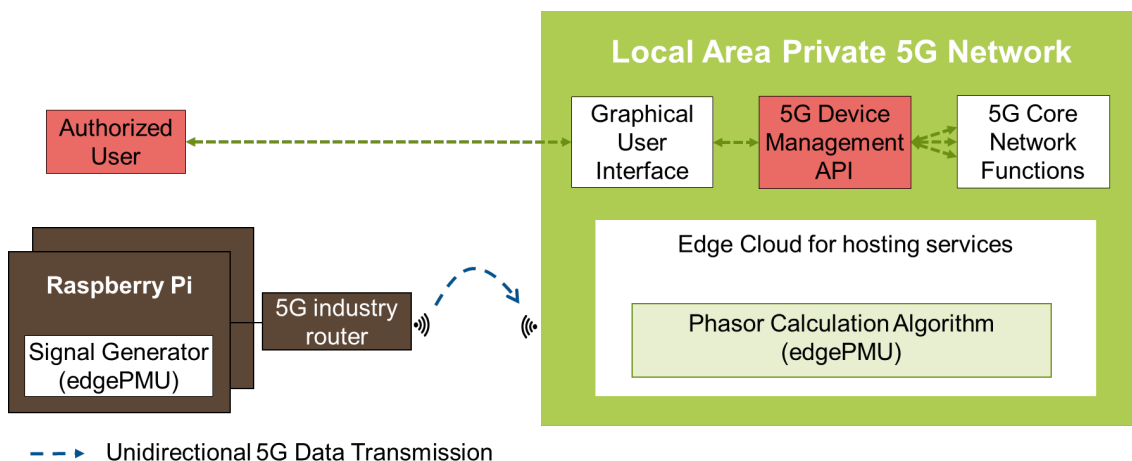


Figure 5-6: The laboratory architecture of the 5G Device Management API proof-of-concept

The edgePMU application deployed in the lab consists of two software components: the signal generator and the phasor calculation algorithm. The signal generator, also referred as sigGen, was installed on multiple Raspberry Pis in the lab, all of which were connected to the 5G industry routers. Each Raspberry Pi connected to the router has its own SIM information including the GPSI and IMSI numbers, to be able to identify the SIMs to the 5G core network. The signal generator generates synthetic data based on simulation results of actual edgePMU readings from the field. This data was transmitted in a single direction towards the phasor calculation algorithm

which is referred as PhasorCalc in the GUI. The PhasorCalc was located on a specifically instantiated virtual machine and hosted on the edge cloud of the lab infrastructure. The algorithm receives the generated data from the signal generator and calculates the phasor information continuously.

In a real-life deployment, multiple edgePMU devices are assumed to be deployed in the field, therefore the communication network will be more complex compared to a single-device case described here. We used the 5G Device Management API to establish the required connectivity between multiple devices and algorithms. Three separate Raspberry Pis and 5G industry routers were used as “Data Acquisition Units” during the tests. Two different virtual machines were instantiated on the edge cloud, each hosting the phasor calculation algorithm. Data acquisition units were separated into two groups: edgePMU1 and edgePMU2. Later, end-to-end connections were established between the group members and related virtual machines in the network. These steps were enabled and completed via the 5G Device Management API and the GUI. Each step is explained in more detail below.

- **Device Provisioning and Onboarding:**

The Device Provisioning and Onboarding feature of the 5G Device Management API allows the easy onboarding of multiple devices without the need for additional help from any third-party mobile operator. In the lab environment, three Raspberry Pis hosting the signal generator were onboarded using the 5G Device Management API. These Raspberry Pis represent the actual measurement devices planned to be deployed in the field, connected to the power grid. Each Raspberry Pi owns a unique GPSI and IMSI number. In Figure 5-1, these three devices had already been onboarded to the network. The names of the devices were determined by the user in the GUI and chosen as “Data Acq. Unit 1-2-3”. In addition, the GPSI numbers of each device are visible to the user on the GUI. The IMSI was only used within the core network, and it was not required to display it.

- **Device Group Creation:**

The Device Group Management function of the 5G Device Management API allows the user to create device groups and modify the memberships of each group. Using that, two device groups were created. The 5G Device Management API allows different QoS parameters to be chosen for each group. These parameters include the maximum uplink and downlink bitrate, and the priority levels. The chosen QoS parameters are automatically applied to all future members of the group. The Figure 5-7 indicates the device group creation screen from the GUI allowing the user to choose QoS parameters.

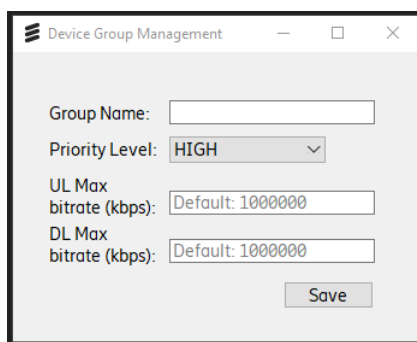


Figure 5-7: Device group creation screen from the GUI

Two groups were created and named EdgePMU1 and EdgePMU2 and they were assigned “HIGH” priority level and default uplink and downlink bitrates. The groups created can be seen in Figure 5-1 and they are indicated as grey rectangles.

- **Group membership for devices:**

The Device Group Management function of the 5G Device Management API allows the user to manage the group membership of each device to any group. In the case indicated

by Figure 5-1, Data Acq Unit 1 and Data Acq Unit 2 were grouped together in the group edgePMU1, while Data Acq Unit 3 was grouped alone in the group edgePMU2. This allows separation between devices.

- **Enabling in-group communication:**

The Device Connectivity Management function of the 5G Device Management API allows the user to provide connection between group members, which is also referred as in-group communication. Using that function, in-group communication was enabled for both edgePMU1 and edgePMU2. After this process, IP addresses were assigned to each device from the 5G core network as seen in Figure 5-1. This allowed edgePMU1, Data Acq Unit 1 and Data Acq Unit 2 to communicate with each other, while Data Acq Unit 3 couldn't reach these devices from the other group. This provides isolation between different devices.

- **Proof of isolation between groups and secure data transfer:**

After establishing the communication network via 5G Device Management API using the GUI, edgePMU data transmission was to test the network. The signal generator deployed in each device was activated and sent data using the UDP protocol. The transmitted data was received via the virtual machine located on the edge cloud and hosting the phasor calculation algorithm. The results showed that all the necessary connections were created successfully, and the secure data transfer was accomplished. The data streams from the device located in edgePMU1 group was not received from the other device located in edgePMU2 group or from the second phasor calculation algorithm instance. Thus, the proof of isolation between groups was achieved.

- **Monitoring the quality of the communication links:**

The Device Connectivity Monitoring function of the 5G Device Management API allows the user to monitor the connection quality of any device instantly. Latency and packet loss measurements were performed for Data Acq. Unit 1 and the result can be seen in the user interface of Figure 5-5. The measurement duration of 100 seconds was chosen, and the packet loss indicates the number of packets lost during that period while latency shows the average latency measured during that period and displays in milliseconds.

- **Disabling in-group communication:**

Using the Device Connectivity Management function, in-group communication was disabled for both edgePMU1 and edgePMU2 which disables communication between members of the same group. After this process was executed, the devices became unreachable for each other even though they are in the same group.

- **Removing devices and groups:**

Using the Device Provisioning and Onboarding and Device Group Management Function, each device was offboarded and each group was removed. This indicates the flexibility and simplicity of the 5G Device Management API for energy industry users.

5.2 Conclusion of this section

In the edgeFLEX project, we have proposed a novel 5G Device Management API which exposes the device management capabilities of 5G networks openly to users, such as power system operators and VPP operators. We have used this prototype 5G Device Management API to demonstrate the increased ease of use of 5G for energy providers and to reduce their need to interact with public 5G network operators.

Our investigations of the requirements placed by the edgeFLEX services and enablers on the 5G Device Management API allowed us to select the relevant API features. These selected features of the 5G Device Management API were implemented in a new GUI as a proof-of-concept demonstrator to illustrate the features of the 5G Device Management API proof-of-concept. As a demonstration of the frontend solution, this GUI was used to create device groups, to establish

the necessary communication links and then to show measurements of packet loss and latency, as shown in the screenshots of the GUI. Additionally, we undertook the integration of the edgePMU software into the 5G laboratory environment in which the 5G network and the 5G Device Management API was available. This integration work validated the successful end-to-end data transmission between data acquisition units and phasor calculation algorithms as a validation of the backend solution.

As a result, our development of a GUI for 5G Device Management API showed that we were able to use an easy-to-use interface to successfully demonstrate features of the API. In addition, we successfully integrated software components of the edgeFLEX platform (one of which is the edgePMU software) with the 5G network and the 5G Device Management API proof-of-concept prototype implementation.

6. Conclusions

The results of our studies demonstrate that we were able to achieve all the objectives of the planned studies:

- Definition of the 5G ICT requirements of the edgeFLEX services and enablers,
- Definition of the 5G API requirements of the edgeFLEX services and enablers,
- Description of the edgeFLEX project efforts to standardize in 3GPP a use case and its requirements, derived from the architecture and capabilities of the edgePMU, enabling data acquisition in the cloud,
- Definition and description of the potential 5G powered solutions in commercial networks that would meet the requirements of the edgeFLEX services as preparation towards exploitation of results, and
- Development of a GUI for the prototype 5G device management API to improve its usability and the demonstration of the increased ease of use which the 5G device management API offers to power system and VPP operators using 5G communications for power services.

Our studies of 5G ICT requirements showed that:

- All the services studied would benefit from the high levels of communication service availability and reliability that 5G networks can offer compared to legacy networks such as LTE although some of the services will operate well with LTE or older networks,
- Some of the services explicitly require the high availability characteristics of 5G to operate correctly,
- 5G networks can meet the latency requirements of all of the edgeFLEX services,
- The latency requirements of the edgePMU (the service which places the highest requirements on latency) of less than 20 ms can be met by 5G, but not by 4G networks, and
- The requirements placed on both the service bit rate and the transfer interval of edgeFLEX services are low except for those of the edgePMU and 5G can support those requirements.

Our studies of appropriate 5G solutions resulted in the definition of solutions using:

- Various architectures and ownership models for 5G networks,
- Private, public and hybrid networks using either edge cloud or central cloud,
- Service enhancements such as network slicing, the URLLC service and proposed 5G device management API,
- Light-weight protocols to assure the security of the edgePMU due to the limited processing power in the edgePMU device, and
- eSIM solutions as an alternative to the proposed 5G device management API for onboarding of devices to 5G networks.

We have defined the timescales and conditions relevant to the deployment of edgeFLEX services in commercial settings.

As the edgePMU enabler places stringent requirements on 5G communications networks, we contributed this particular use case to the 3GPP SA1 standardisation group and are pleased that the submission was accepted and published as an enhancement to the previously existing 5G standards.

We have proposed a 5G device management API to improve the ease of use of 5G by energy providers and to reduce their need to interact with public 5G network experts or public operators, if a public rather than a private 5G network is being used. The features selected for demonstration of the novel prototype 5G Device Management API supporting edgeFLEX services were derived from the requirements of the edgeFLEX services. A new GUI to existing API proof-of-concept implementations was implemented to show the selected API features supporting the edgePMU enabler, validating the API functionality as a proof-of-concept demonstrator.

7. List of Tables

Table 2-1: Voltage Control Service Overview	9
Table 2-2: Inertia Estimation Overview	10
Table 2-3: Frequency Regulation Metering Service Overview.....	11
Table 2-4: VPP Coordinated Frequency Control Service Overview	12
Table 2-5: VPP Automated Generation Control Service Overview.....	13
Table 2-6: VPP Optimisation Service Overview.....	14
Table 2-7: Advanced Energy Flexibility Service Overview.....	16
Table 2-8: edgePMU overview	17
Table 2-9: Communication characteristics of the edgeFLEX services and enablers.....	18
Table 3-1: 5G ICT requirements for edgeFLEX services and enablers	22
Table 3-2: The 5G Device Management API Features and the API related requirements of edgeFLEX services and enablers	23
Table 3-3: Overview of the 5G Device Management API Features.....	23
Table 3-4: Physical conditions of device deployments in slow and fast dynamics in Wunsiedel Germany relevant for 5G installation.....	24
Table 3-5: Physical conditions of device deployments in fast dynamics in Italy relevant for 5G installation.....	25
Table 4-1: 5G solutions for edgeFLEX services and enablers.....	31
Table A.1-1: 5G requirements for Voltage Control service	53
Table A.1-2: 5G requirements for Inertia Estimation service	54
Table A.1-3: 5G requirements for Frequency Regulation Metering service.....	55
Table A.1-4: 5G requirements for Coordinated Frequency Control service.....	56
Table A.1-5: 5G requirements for Automated Generation Control service	57
Table A.1-6: 5G requirements for VPP Optimization service.....	58
Table A.1-7: 5G requirements for Energy Flexibility Trading service.....	59
Table A.1-8: 5G requirements for edgePMU.....	60

8. List of Figures

Figure 2-1: Voltage Control Service Diagram	9
Figure 2-2: Inertia Estimation Service Diagram	10
Figure 2-3: Frequency Regulation Metering Service Diagram.....	11
Figure 2-4: VPP Coordinated Frequency Control Service Diagram.....	12
Figure 2-5: VPP Automated Generation Control Service Diagram	13
Figure 2-6: VPP Optimisation Service Diagram	14
Figure 2-7: Advanced Energy Flexibility Service Diagram.....	15
Figure 2-8: edgePMU Service Diagram	16
Figure 2-9: An exemplary edgeFLEX Functional Architecture with the 5G Device Management API.....	17
Figure 5-1: The GUI for the 5G Device Management API – proof-of-concept demonstrator.....	39
Figure 5-2: Device box from the GUI	39
Figure 5-3: Application box from the GUI.....	40
Figure 5-4: Device group box from the GUI	40
Figure 5-5: Device connectivity monitoring screen from the GUI.....	41
Figure 5-6: The laboratory architecture of the 5G Device Management API proof-of-concept ..	41
Figure 5-7: Device group creation screen from the GUI	42

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10. List of Abbreviations

3GPP	Third Generation Partnership Project	ICT	Information and Communications Technology
5G	Fifth Generation	IE	Inertia Estimation
AGC	Automated Generation Control	IMSI	International Mobile Subscriber Identity
AP	Access Point	IP	Internet Protocol
API	Application Programmable Interface	KB	Kilo Byte
APN	Access Point Name	LMR	Land Mobile Radio
CFC	Coordinated Frequency Control	LTE	Long Term Evolution
CoAP	Constrained Application Protocol	MQTT	MQ Telemetry Transport
DAQU	Data Acquisition Unit	MTC	Machine-Type Communication
DER	Distributed Energy Resources	MV	Medium Voltage
DL	Downlink	NA	Not Applicable
DSO	Distribution System Operator	NB	Narrow Band
EC-GSM IoT	Extended Coverage GSM for Internet of Things	NPN	Non-Public Network
EFT	Energy Flexibility Trading	OSCORE	Object Security for Constrained RESTful Environments
EMS	Energy Management Systems	PMU	Phasor Measurement Unit
eSIM	embedded Subscriber Identification Module	POC	Point of Connection
FEMS	Factory Energy Management System	RES	Renewable Energy Sources
FFR	Fast Frequency Regulation	REST	Representational state transfer
FOA	Flexibility Offer Agent	RF	Radio Frequency
FRM	Frequency Regulation Metring	RoCoP	Rate-of-Change-of-Power
GUI	Graphical User Interface	SA	Stand Alone
GPS	Global Positioning Service	SCADA	Supervisory Control and Data Acquisition
GPSI	Generic Public Subscription Identifier	SIM	Subscriber Identity Module
GSM	Global System for Mobile Communications	SO	System Operator
HW	Hardware	TLS	Transport Layer Security
		TSN	Time Sensitive Network

TSO	Transmission System Operator
UDP	User Datagram Protocol
UE	User Equipment
UICC	Universal Integrated Circuit Card
UL	Uplink
URLLC	Ultra-Reliable Low Latency Communication
VC	Voltage Control
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
VPP	Virtual Power Plant
WP	Work Package

ANNEX

A.1 edgeFLEX services and enablers and their 5G context

A.1.1 Voltage control

The communication direction in voltage control is bi-directional, i.e., both uplink and downlink. Data is sent from the device to the algorithm and the control messages are sent from the algorithm to the device. In this service, the edge of the network (substations) and the distributed energy resources are communicating.

Number of endpoints

In phase 1, in which only the communication between the grid and the service algorithms is considered, the number of devices is small. When entering phase 2, the information from the market is exploited and number of devices increases. The service area covers several km² up to 100,000 km².

Latency

The latency is foreseen to be 100ms to 500ms. It is measured as round-trip time, i.e., the time between the taking of the measurement by the field device and the receiving of the control message.

Sampling rate

For the uplink and downlink streams, the sampling rate is 1 to 10 messages per second.

Message volume

The message size is between 10kB and 100kB. It is smaller than 1kB, if MQTT is used. For uplink, the size has at maximum six values because the voltage and/or the current has one or three phases. For downlink, the size has at maximum two values as the message will carry a set point for active and/or reactive power. Two measurements from each DER of type double are minimum (voltage and active power).

Reliability

Since the voltage control is only activated in the case of an overvoltage or undervoltage, a missing packet affects the performance. As an effect, the reliability of the service is high.

Availability

To ensure a safe operation without interruptions, the availability of communication is high.

Security

Since voltage control is a sensitive service, a very high security is important. The service communicates with external sources, owned and managed by grid operators, in order to receive updates of the grid configuration and to transmit control messages. Thus, protection from external influences is fundamental.

The following table shows the 5G requirements for Voltage Control service.

Table A.1-1: 5G requirements for Voltage Control service

5G requirements	Voltage Control service
Req-VC-endPoints	Phase 1: small, phase 2: high, several km ² up to 100,000 km ²
Req-VC-latency	100ms – 500ms
Req-VC-sampleRate	1 to 10 messages per second
Req-VC-volume	4 values of type float and time stamp, 10KB – 100KB, 1KB for MQTT
Req-VC-reliability	High
Req-VC-availability	High
Req-VC-security	Very high

A.1.2 Inertia estimation

Inertia estimation is one of the monitoring services and has a uni-directional communication, i.e., the message is sent from the field device to the algorithm. This is a not critical monitoring service.

Number of endpoints

More number of endpoints are advantageous for the measurements. However, the number is limited by power generation substations. The density of nodes is less than one per km².

Latency

The one-way latency is between 1ms and 100ms. Since the service is based on post-processing of time-stamped data, it runs over a long period and a maximum latency is not an issue.

Sampling rate

The data is sampled by a rate of 1 to 100 messages per second.

Message volume

Two measurements (frequency and active power) are taken. Each measured quantity is of type float.

Reliability

Due to the post-processing of time-stamped data, no strict requirements are needed.

Availability

Since the service post-processes time-stamped data, packet loss will not affect the estimation. A standard level of availability is sufficient.

Security

High security is needed, but without data encryption.

The following table shows the 5G requirements for Inertia Estimation service.

Table A.1-2: 5G requirements for Inertia Estimation service

5G requirements	Inertia Estimation service
-----------------	----------------------------

Req-IE-endPoints	<1 per km2, several km2 up to 100,000 km2
Req-IE-latency	Not an issue, 1ms – 100ms
Req-IE-sampleRate	1 to 100 messages per second
Req-IE-volume	Two values of type float, timestamp
Req-IE-reliability	Standard
Req-IE-availability	Standard
Req-IE-security	High, no encryption

A.1.3 Frequency control concepts

A.1.3.1 Frequency regulation metering

Frequency regulation metering is a not critical monitoring service.

Number of endpoints

Since measurements of neighbouring buses are needed, the number of endpoints is limited and can cover an area of several km2 up to 100,000km2.

Latency

Latency is not an issue. It should have a value around 100ms.

Sampling rate

The service samples 0.1 up to 10,000 messages per second.

Message volume

Frequency measurements from all neighbouring buses are needed. Each measurement is of type float.

Reliability

A normal level of reliability is beneficial, so that there are no strict requirements.

Availability

A standard level of availability is sufficient.

Security

High security is needed, but without data encryption.

The following table shows the 5G requirements for Frequency Regulation Metering service.

Table A.1-3: 5G requirements for Frequency Regulation Metering service

5G requirements	Frequency Regulation Metering service
Req-FRM-endPoints	<1 per km2, Several up to 100,000 km2

Req-FRM-latency	Not an issue, Around 100ms
Req-FRM-sampleRate	0.1 up to 10,000 messages per second
Req-FRM-volume	Each value of type float
Req-FRM-reliability	High
Req-FRM-availability	High
Req-FRM-security	High, no encryption

A.1.3.2 VPP coordinated frequency control

Frequency control is critical service using bi-directional communication.

Number of endpoints

The number of nodes is between 10 and 100.

Latency

Latency is a relevant issue because it affects the accuracy of the service and the stability of the system. Its value is around 100ms.

Sampling rate

The sampling rate varies between 0.1 and 10,000 messages per second.

Message volume

A message has two values of type float and time stamp.

Reliability

A high level of reliability is beneficial, but there are no strict requirements.

Availability

A standard level of availability is sufficient.

Security

High security is needed, but without data encryption.

The following table shows the 5G requirements for Coordinated Frequency Control service.

Table A.1-4: 5G requirements for Coordinated Frequency Control service

5G requirements	Coordinated Frequency Control service
Req-CFC-endPoints	10's to 100's, Several up to 100,000 km ²
Req-CFC-latency	Relevant, around 100ms
Req-CFC-sampleRate	0.1 up to 10,000 messages per second
Req-CFC-volume	Two values of type float and time stamp

Req-CFC-reliability	High
Req-CFC-availability	High
Req-CFC-security	High, no encryption

A.1.3.3 VPP automated generation control

Automated generation control (AGC) is a less critical secondary control service.

Number of endpoints

The number of nodes is between 10 and 100.

Latency

Latency is not an issue and has a value of 1s.

Sampling rate

The service samples 0.1 up to 10,000 messages per second.

Message volume

A message has one value of type float and time stamp.

Reliability

A high level of reliability is beneficial, but there are no strict requirements.

Availability

A high level of availability is useful for the service.

Security

High security is needed, but without data encryption.

The following table shows the 5G requirements for Automated Generation Control service.

Table A.1-5: 5G requirements for Automated Generation Control service

5G requirements	Automated Generation Control service
Req-AGC-endPoints	10's to 100's, Several up to 100,000 km2
Req-AGC-latency	Not an issue, 1s
Req-AGC-sampleRate	0.1 up to 10,000 messages per second
Req-AGC-volume	One value of type float and time stamp
Req-AGC-reliability	High
Req-AGC-availability	High
Req-AGC-security	High, no encryption

A.1.4 VPP Optimization

The edgeFLEX service VPP optimization uses bi-directional communication. Forecasting and stochastics models are not taken into consideration in this ICT requirements.

Number of endpoints

The number of nodes is up to 1000 nodes. In the moment, there is one endpoint per facility, 10 per VPP and 1000 per country. In the future, the number of endpoints will increase due to smaller facilities.

Latency

For fast dynamic systems, the one-way latency is smaller than 400ms. In contrast, slow dynamics is smaller or equal that 5s.

Sampling rate

The messages are samples with a rate of one message per second.

Message volume

Each message has two values and time stamp.

Reliability

The reliability is critical because the loss of one packet leads to a VPP which is operated as currently. Especially, the market connection is more critical than weather information.

Availability

A high availability of 99.99% is proposed as default value although it is usually part of commercial negotiations.

Security

A standard security is needed including data encryption.

The following table shows the 5G requirements for VPP Optimization service.

Table A.1-6: 5G requirements for VPP Optimization service

5G requirements	VPP Optimization service
Req-VPPO-endPoints	1 node per facility, 10 nodes per VPP, 1000 nodes per country
Req-VPPO-latency	Fast dynamics: <400ms, slow dynamics: <=5s
Req-VPPO-sampleRate	UL: 1 message per 15min, DL: when it is needed
Req-VPPO-volume	Two values and time stamp
Req-VPPO-reliability	High
Req-VPPO-availability	High, target 99.99%
Req-VPPO-security	high with encryption

A.1.5 Advanced energy flexibility aggregation and trading system

This service uses a bi-directional communication link.

Number of endpoints

The flexibility offer agent (FOA) and the flexibility trading platform are relevant endpoints. Any electricity device can be connected to the flexibility offer agent. The density depends on the use case.

Latency

Latency is not critical. It is differentiated between two concepts. Reactive power trading needs latency less than 100ms (round-trip), reactive power management less than 20ms (round-trip).

Sampling rate

In uplink, the sampling rate has a value of one message per 15s up to one message per 1ms. It depends on the concept, i.e., if reactive power trading or management is the current use case. In downlink, stochastics and the use case influence the sampling rate. The downlink is sampled more often, if many problems occur.

Message volume

There are three different messages. The type 1 heartbeat message sent by the prosumers has the values operation power, operation prognosis and operation station as well as a time stamp. The type 2 heartbeat message sent by the prosumers and segmented by priority contains priority, interval length, accounting power, operation power, operation prognosis and operation state as well as time stamp. The flex offer message sent by flexibility market operator includes flex offer profile constraints and a time stamp.

Reliability

-

Availability

The availability is important, but not critical. There is a mechanism in the flexibility offer agent so that all the control is performed locally. As a result, no damage is caused in case of lacking communication.

Security

Security is important between the flexibility offer agent and the trading platform. Online communications are encrypted using TLS.

The following table shows the 5G requirements for Energy Flexibility Trading service.

Table A.1-7: 5G requirements for Energy Flexibility Trading service

5G requirements	Energy Flexibility Trading service
Req-EFT-endPoints	Depends on use case
Req-EFT-latency	Power trading: <100ms, power management: <20ms
Req-EFT-sampleRate	1 message per 15s up to 1s
Req-EFT-volume	3 to 6 values and time stamp

Req-EFT-reliability	Critical
Req-EFT-availability	Important, not critical
Req-EFT-security	Encryption

A.1.6 edgePMU

This service uses a unidirectional communication link.

Number of endpoints

-

Latency

< 33 ms

Sampling rate

1 message per 1 ms

Message volume

-

Reliability

> 1 year

Availability

99.999%

Security

High

The following table shows the 5G requirements for edgePMU.

Table A.1-8: 5G requirements for edgePMU

5G requirements	edgePMU
Req-edgePMU-endPoints	-
Req-edgePMU-latency	< 33 ms
Req-edgePMU-sampleRate	1 message per 1 ms
Req-edgePMU-volume	-
Req-edgePMU-reliability	> 1 year
Req-edgePMU-availability	99.999%
Req-edgePMU-security	High

A.2 Requirements of edgeFLEX services and enablers related to the 5G Device Management API

A.2.1 Remote orchestration of the group of devices

- **Short description:** Enable remote orchestration of multiple devices as a group
- **Detailed description:** This use case is being developed in the university lab of our partners where the model running in the network is dispatching the algorithm or the configurations to the deployed devices. In the commercial implementation the devices will be deployed in the power network in distributed manner. One use case could be distribution of applications or configurations to battery storage devices.
- **Advantages:** This use case has potential to be applied in many scenarios or energy services, e.g., VPP assets management.
- **Solution:** The 5G Device Management API will enable the user/energy application to orchestrate group of devices. E. g., if the devices are serving the same-purpose and/or collecting the same data from the field, they can be grouped together and managed as a group.

A.2.2 Automatic software deployment of low-cost devices (edgePMUs)

- **Short description:** Automatically deploying a software to the low-cost devices in the field
- **Detailed description:** Currently, phasor measurement units (PMUs) are placed in substations, and they are very expensive. The new concept of the low-cost power measurement devices, edgePMUs, where the data processing is executed in the edge cloud, is being developed in the edgeFLEX project. The software deployment of the device currently needs to be done individually per each device using secured dedicated communications. The requirement is that the software deployment is done remotely and automatically from the application on edge cloud to the devices located in the field.
- **Advantages:**
 - The possibility to deploy low-cost devices on the field without a need to buy the traditional phasor measurement units with the post-processing application embedded to them.
 - As it is possible to update or change the software on the devices, one device can be used for several purposes depending on its configuration.
- **Solution:** Through the 5G Device Management API, it is possible to establish end-to-end connections between edgePMU devices located in the field and data processing applications hosted on edge cloud. After the end-to-end connection is established through the API, this communication link can be used to push any software or the software update to the edgePMU devices deployed in the field. However, this can only be done automatically, in case the application/s hosted on edge cloud has this kind of functionality, since this is not a feature of the 5G Device Management API.

A.2.3 Identification of the VPP assets ensured through underlying 5G communications

- **Short description:** Securely identifying the VPP assets through the authentication methods used in 5G without a need to use computationally loaded cryptographic methods
- **Detailed description:** Currently the communication among the user (the VPP management application) and the VPP assets relies on cryptographic controls like bidirectional X509 certificates that put computational load on the devices that are normally limited in the processing capacity. Therefore, in case the identification of various VPP assets can be done through the 5G or 5G Device Management API, it would decrease the load on devices.

- **Advantages:**
 - The user will have much more confidence of the identity of the devices that communicate with the cloud platform (or edge cloud).
 - Computational load on the devices will be decreased.
 - 5G will enable authentication of the devices.
 - Putting the identification on 5G layer is an optimal way to ensure standardised and secured authentication solution.
- **Solution:** The 5G Device Management API enables the authentication and identification of the devices with the subscription identification numbers (e.g., SIM card details of devices such as IMSI or GPSI numbers).

A.2.4 Direct communications with the edge devices without using IoT gateways

- **Short description:** Providing end-to-end connections between VPP assets and applications hosted on cloud/edge cloud without a need to use IoT gateways
- **Detailed description:** For the communication from the cloud to the VPP assets, additional HW component (IoT gateway) is necessary at the moment. This will be even bigger issue in the future, when a high number of distributed VPP assets need to be connected to the management applications running in the cloud/edge cloud.
- **Advantages:**
 - No need to buy an extra hardware, which saves installation and maintenance costs of the extra hardware.
- **Solution:** When the VPP assets are capable of communicating via 5G, meaning that when they have SIM cards and/or 5G modems connected to the non-5G capable devices, then the 5G Device Management API can enable direct and end-to-end communication between the VPP assets and VPP management applications hosted on cloud/edge cloud with its “device provisioning and onboarding”, “device grouping” and “device connectivity management” features.