5G Solutions for European Citizens

D5.2-D5.2B: LL field trials (phase 2)

Document Summary Information

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<tr>
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<td>Silvia Canale</td>
</tr>
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1 According to 5G Solutions Quality Assurance Process:
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3 months before Deliverable’s Due Date: 50% should be complete
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# Table of Contents

1 Executive Summary .................................................................................................................. 10
2 Introduction ................................................................................................................................. 11
  2.1 Mapping Projects’ Outputs ....................................................................................................... 11
  2.2 Deliverable Overview and Report Structure ........................................................................... 12
3 LL2 field trials phase 2 .................................................................................................................. 15
  3.1 *UC2.1 Industrial Demand Side Management* ........................................................................ 15
    3.1.1 Use Case Technical Design, Implementation and Integration ........................................... 16
    3.1.2 Overview of the Test Setup According to the Plan ............................................................ 29
    3.1.3 *Execution of Test Case TC2.1.1* ................................................................................... 30
    3.1.4 *Execution of Test Case TC2.1.3* .................................................................................... 31
    3.1.5 Effect of the COVID .......................................................................................................... 35
    3.1.6 Mitigation Measures ......................................................................................................... 35
    3.1.7 Next Steps ....................................................................................................................... 35
  3.2 *UC2.2 Electric Vehicle Smart Charging* .............................................................................. 35
    3.2.1 Use Case Technical Design, Implementation and Integration ........................................... 37
    3.2.2 Overview of the Test Setup According to the Plan Described in D2.4B ................................ 48
    3.2.3 *Execution of Test Case TC2.2.4* ................................................................................... 51
    3.2.4 *Execution of Test Case TC2.2.6* .................................................................................... 53
    3.2.5 Effect of the COVID .......................................................................................................... 55
    3.2.6 Mitigation Measures ......................................................................................................... 56
    3.2.7 Next Steps ....................................................................................................................... 56
  3.3 *UC2.3 Electricity Network Frequency Stability* .................................................................... 56
    3.3.1 Use Case Technical Design and Implementation ............................................................... 58
    3.3.2 Overview of the Test Setup According to the Plan Described in D2.8 – D2.4A .................. 77
    3.3.3 *Execution of Test Case TC2.3.1* .................................................................................... 78
    3.3.4 *Execution of Test Case TC2.3.2* .................................................................................... 80
    3.3.5 Effect of the COVID .......................................................................................................... 83
    3.3.6 Mitigation Measures ......................................................................................................... 83
    3.3.7 Next Steps ....................................................................................................................... 83
4 LL3 – Smart city and ports ............................................................................................................. 84
5 Conclusions and Next Actions .................................................................................................... 85
6 References .................................................................................................................................... 88
List of Figures

Figure 1 Reference architecture: (A) for TC2.1.1, (B) for TC2.1.2, and (C) for TC2.1.3 .................................................. 16
Figure 2 Reference architecture specialized for TC2.1.1 .................................................................................. 17
Figure 3 Deployment architecture of TC2.1.1 ............................................................................................. 18
Figure 4 UC2.1 Vertical Service Blueprint for TC2.1.1 ......................................................................... 19
Figure 5 UC2.1 Context Blueprint for TC2.1.1 ....................................................................................... 20
Figure 6 LL2 reference architecture specialized for TC2.1.3 ................................................................. 22
Figure 7 Deployment architecture for TC2.1.3 ......................................................................................... 22
Figure 8 Local Controller - Hardware architecture ............................................................................. 24
Figure 9 Local Controller – Software architecture ............................................................................. 25
Figure 10 Remote Controller - Software architecture ......................................................................... 26
Figure 11 Vertical Service Blueprint for TC2.1.3 ................................................................................. 27
Figure 12 UC2.1 Context Blueprint for TC2.1.3 .................................................................................. 27
Figure 13 Pre-trial 5G connectivity test in the test field ...................................................................... 32
Figure 14 Huawei CPE Pro 5G modem-router for TC2.1.3 .............................................................. 32
Figure 15 PoC Set up for TC2.1.3 ........................................................................................................... 33
Figure 16 HA client hosted in the Local Controller (PoC) for TC2.1.3 ............................................... 33
Figure 17 One of the loads in the execution of the test case in TC2.1.3 ............................................... 34
Figure 18 UC2.1 measurement process description ........................................................................ 35
Figure 19 UC2.2 – Reference architecture ........................................................................................ 36
Figure 20 TC 2.2.4 (B) and TC 2.2.5 (C) deployment architecture from general UC 2.2 architecture (A) .......... 38
Figure 21 Old CSP layer architecture ........................................................................................................... 39
Figure 22 Updated CSP layer architecture ......................................................................................... 39
Figure 23 CSP Back-end: periodical communication with E-Mobility Platform and Master Control Agent VNF for TC2.2.6 ............................................................................................................ 41
Figure 24 Use Case 2.2 - Discovery of Local Control Agents ........................................................... 42
Figure 25 Use Case 2.2 - Decentralized optimization problem iteration ........................................... 43
Figure 26 Use Case 2.2 - Decentralized optimization problem at its last iteration (optimal solution found) ...... 44
Figure 27 Vertical Service Blueprint for TC2.2.4 and TC2.2.6 .......................................................... 46
Figure 28 Context Blueprint for TC2.2.4 and TC2.2.6 ................................................................. 47
Figure 29 UC2.2 test site for trial activities ........................................................................................... 49
Figure 30 Energy facility set up for TC2.2.6 ............................................................................................... 49
Figure 31 The EVs in Test Case TC2.2.6 ..................................................................................................... 50
Figure 32 TC 2.2.4 deployment architecture ....................................................................................... 52
Figure 33 Laptop connected via ethernet cable for TC2.2.4 .............................................................. 53
Figure 34 TC 2.2.6 deployment architecture .................................................................54
Figure 35 Test Case TC2.2.6 Load Area (a) and Vehicle State of Charge (b) .................55
Figure 36 UC 2.3 - Reference architecture ..................................................................57
Figure 37 Frequency regulation with EV connected to a charging station (but not in charge) ......................60
Figure 38 Frequency Regulation with EV charging with maximum power ..................60
Figure 39 Example of the superposition of smart charging and frequency regulation services: (top) network frequency time evolution and (bottom) associated charging session ..................................61
Figure 40 linear interpolation. a) p-f curve of two EVs, b) cumulative p-f curve ..................62
Figure 41 linear interpolation with load area control: (a) p-f curve of for two EVs and (b) cumulative p-f curve 63
Figure 42 Global droop curve with associated relevant parameters ..................................65
Figure 43 Local droop curve with associated relevant parameters ..................................65
Figure 44 Scenario 1 - Balanced condition: resulting local and global droop curves ..........68
Figure 45 Scenario 1 - Balanced conditions: fraction of the maximum PEV power margin used for each PEV ....69
Figure 46 Scenario 1 - Different power margins: resulting local and global droop curves (request of 50% of the overall power margins) ..........................................................69
Figure 47 Scenario 1 - Different power margins: fractions of the maximum PEV power margin used for each PEV (request of 50% of the overall power margins) ........................................69
Figure 48 Scenario 2 – Balanced margins and unbalanced SOC errors: resulting local and global droop curves (request of 70% of the overall power margins) ..............................................70
Figure 49 Scenario 2 – Balanced margins and unbalanced SOC errors: fractions of the maximum PEV power margin used for each PEV (request of 70% of the overall power margins) ..................71
Figure 50 Simulation with 1000 PEVs ...........................................................................72
Figure 51 Use Case 2.3 Detailed Sequence Diagram ......................................................73
Figure 52 Vertical Service Blueprint (VSB) for UC 2.3 ....................................................74
Figure 53 Latency decomposition of Frequency Regulation control loop .......................75
Figure 54 UC2.3 - Test site for trial activities .................................................................77
Figure 55 UC2.3 site for trial activities (in blue) and the Italian Site of the 5G EVE platform (in yellow) ........78
Figure 56 Test Case 2.3.1 deployment architecture .......................................................79
Figure 57 Test Case 2.3.2 deployment architecture .......................................................81
Figure 58 Gobmaier micromax-f Frequency Meter used in Test Case 2.3.2 ......................82
List of Tables

Table 1 Adherence to 5G-Solutions GA Deliverable & Tasks Descriptions ................................................................. 12
Table 2 Federated MySql Table ‘comandi’ .................................................................................................................. 18
Table 3 Federated MySql Table ‘misure_periodiche’ .................................................................................................... 19
Table 4 List of Vertical Service and Network KPIs for UC2.1.1 .................................................................................... 20
Table 5 API list to the KPIs-VS for TC2.1.1 in Cycle 1 ............................................................................................... 21
Table 6 CDSO Implementation for TC2.1.3 .................................................................................................................. 27
Table 7 Reference KPIs for TC2.1.3 in Cycle 1 ........................................................................................................... 28
Table 8 API list to the KPI-VS for TC2.1.3 in Cycle 1 .................................................................................................. 29
Table 9 List of Charge Advisor’s interfaces .............................................................................................................. 40
Table 10 List of Vertical Service and Network KPIs for TC2.2.4 and 2.2.6 ................................................................. 47
Table 11 API list to the KPI-VS for TC2.2.4 and TC2.2.6 in Cycle 2 ............................................................................. 48
Table 12 Charging sessions ........................................................................................................................................ 69
Table 13 Charging sessions ........................................................................................................................................ 70
Table 14 List of Vertical Service and Network KPIs ................................................................................................... 76
Table 15 API list to the 5G-Solutions KPIs VS for TC2.3.3 in Cycle 1 ......................................................................... 76
## Glossary of terms and abbreviations used

<table>
<thead>
<tr>
<th>Abbreviation / Term</th>
<th>Description</th>
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<tbody>
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<td>acknowledge</td>
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<tr>
<td>ADMM</td>
<td>Alternative Direction Method of Multipliers</td>
</tr>
<tr>
<td>AF</td>
<td>application function</td>
</tr>
<tr>
<td>aFRR</td>
<td>Frequency Restoration Reserves with Automatic activation</td>
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<td>ATU</td>
<td>Accumulated Thermal Units</td>
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<td>ADMM</td>
<td>Battery Management System in UC2.2</td>
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<td>CDSO</td>
<td>5G-Solutions Cross-Domain Service Orchestrator</td>
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<td>Context Descriptors</td>
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<td>enhanced mobile broadband</td>
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<tr>
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</tr>
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<td>Experiment Descriptor</td>
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<td>FTTC</td>
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<td>GUI</td>
<td>Graphic User Interface</td>
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<td>Home Assistant</td>
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<td>Human Machine Interface</td>
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<td>HTTP</td>
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<td>HTTPS</td>
<td>Secure Hypertext Transfer Protocol</td>
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<td>Abbreviation</td>
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<td>HVAC</td>
<td>Heating, Ventilation and Air Conditioning</td>
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<td>KPI</td>
<td>Key Performance Indicator</td>
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<td>5G-Solutions KPI visualization system</td>
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<td>LL</td>
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<td>massive machine type communications</td>
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<td>MPC</td>
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<td>new radio</td>
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<tr>
<td>PEV</td>
<td>Plug-in Electric Vehicle</td>
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<tr>
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<tr>
<td>PoC</td>
<td>Proof-of-Concept</td>
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<tr>
<td>QoS</td>
<td>quality-of-service</td>
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<tr>
<td>QP</td>
<td>Quadratic Programming</td>
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<td>RAN</td>
<td>Radio Access Network</td>
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<tr>
<td>RES</td>
<td>Renewable Energy Source</td>
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<td>RMCU</td>
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<td>Raspberry Pi</td>
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<td>Remote Terminal Unit</td>
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<tr>
<td>SA</td>
<td>standalone</td>
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<td>UC</td>
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<td>User Equipment</td>
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<tr>
<td>URLLC</td>
<td>ultra-reliable low-latency communications</td>
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<tr>
<td>UVAM</td>
<td>Mixed Enabled Virtual Unit</td>
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<td>V1G</td>
<td>Unidirectional Vehicle to Grid</td>
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<td>V2G</td>
<td>Vehicle to Grid</td>
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<tr>
<td>VL</td>
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<td>Virtual Machine</td>
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<td>Virtualized Network Function</td>
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<td>WLAN</td>
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1 Executive Summary

The scope of this document is to provide a detailed analysis and demonstration of the field trials of the Living Lab Smart Energy (LL2) and smart city and ports in Cycle 2. The LL2 focuses on Smart energy applications with a specific attention to Demand Side Management. The document describes the conditions under which the trials are executed for the different use cases (UCs) of LL2. The purpose of each test case being executed in Cycle 2, the technical issues and the challenges, the execution plan, the effect of different risk categories and related mitigation plans, and next steps for Cycle 3 from LL2 are reported, while results and lessons learned are reported in D5.3B.

The **Smart energy LL** targets three use cases referring to the broad area of Demand Side Management (DSM). DSM refers to the changes in electricity use by consumers from their normal consumption patterns in response to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardised. In a broader sense, DSM also embeds the topic of overload avoidance and optimal self-consumption in those scenarios where the peak power affects the energy bill, and local Renewable Energy Source (RES) have an impact on the net power withdrawn from the grid. The particular use cases to be validated in the project through the 5G facility provided by the ICT-17 5G EVE platform are as follows:

- **UC2.1:** Industrial Demand Side Management.
- **UC2.2:** Electrical Vehicle (EV) Smart Charging.
- **UC2.3:** Electricity network frequency stability.

By digital and telecommunication technologies, traditional networks and services become more efficient for the citizens and businesses benefit. It is estimated that 12 billion devices will be connected to mobile networks by 2022, while a large proportion of communications will occur between machines and not humans. In this respect, 5G supporting massive machine type communications (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable low-latency communications (URLLC) will be able to meet the heterogenous and stringent requirements of the two LLs at hand, namely, Smart Energy (LL2). The use cases selected for trials in LL2 require reliable connectivity and high device density in urban areas, where the most of energy loads typically used by citizenship are concentrated.

In addition to the document a video has been produced, describing the other soul of WP5, i.e, smart city and ports, available in the folder [https://drive.google.com/drive/folders/1PtIkIltqxMovj1le1TbiQA4A02Xfq0T?usp=sharing](https://drive.google.com/drive/folders/1PtIkIltqxMovj1le1TbiQA4A02Xfq0T?usp=sharing)
2 Introduction

The 5G-Solutions project targets to explore various 5G verticals, set them up based on ICT-17 projects infrastructure, measure various KPIs from the network and application sides and show if the 5G infrastructure provides the required quality-of-service (QoS) for the different 5G use cases.

Among a set of 20 defined use cases for four different LLs, this deliverable is focused on field trials and executions of 3 use cases collectively from LL2 (Smart Energy), all of them participating to the field trials in Cycle 2. This deliverable, hence, aims to describe the Cycle 2 field trials and the planned executions of these use cases, which are expected to shape the future of 5G networks and applications to identify:

- The purpose of each use case test.
- The test setup and architecture.
- The main challenges of implementing each use case.
- The planned execution of the use cases.
- The impact of Covid-19 on the use case testing progress and the proper mitigation measures.
- Next steps of each use case field trials.

This is the second drop of three reports planned for deliverable D5.2 (namely, D5.2B). The deliverable is in line with the contributions given in previous deliverables D1.1A, D1.1A-rev, and D1.1B, as well as D2.4A and D2.4B, which include the detailed requirements of each use case and the status and deployment reference framework from the ICT-17 project and facility which LL2 deploys all the use cases, namely the 5G EVE platform. Moreover, the different test areas and test cases of the different use cases and their planned executions against the respective test cycles of the project were illustrated in these deliverables. This document focuses solely on the information relevant to Cycle 2 of the experiments and reports on field trials for LL2 use cases in Cycle 2.

The field trials in Cycle 2 will be progressed incrementally through the final cycle of the project (i.e., Cycle 3). Hence, the final cycle will be built upon (and driven by) the progress so far of Cycle 1 and Cycle 2. The results here reported are an advancement with respect D5.2 A and are seminal to the subsequent deliverable D5.2C. In other words, this deliverable will be the cornerstone for the 5G field trials for LL2, by defining in a clear and solid way the test setup and architecture, purpose of the tests, challenge, and mitigation measures, and also the next steps of the field trials for the industry vertical smart energy.

Two of the three use cases of LL2 started their field trials in Cycle 1, while all of them participated in Cycle 2 and contributed to this deliverable. More specifically, the Use Cases from LL2 that confirmed their field trials for Cycle 2 experiments include:

1. UC2.1: Industrial Demand Side Management.
2. UC2.2: Electrical Vehicle (EV) Smart Charging.
3. UC2.3: Electricity network frequency stability.

The selection and definition process for the test cases’ description, analysis and design has been conceived in Task 1.4 and all use case developers in LL2 have been involved in the first-round test case definition activity supported by partners in Task 1.4. A preliminary version of documentation concerning test case design has been reported in D1.4A. The definition of the use cases’ test areas and test cases are also defined in D2.4A and updated in D2.4 B. Among those defined in D2.4B, Cycle 2 field trials for test cases of UCs in LL2 are reported here in this document with the involved Verticals, through ICT-17’s 5G EVE platform.

2.1 Mapping Projects’ Outputs

The main purpose of this section is to map 5G-Solutions Grand Agreement commitments, both within the formal Deliverable and Task description, against the project’s respective outputs and work performed. Please refer to the table below for this mapping.
Table 1 Adherence to 5G-Solutions GA Deliverable & Tasks Descriptions

<table>
<thead>
<tr>
<th>Project GA Component Title</th>
<th>Project GA Component Outline</th>
<th>Respective Document Chapters</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DELIVERABLE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D5.2B: Living Lab field trials (V2.0)</td>
<td>Actual field trials of all Living Labs, repeated over 3 iterative testing cycles, one per 3GPP release</td>
<td>Chapter 3 provides technical information on LL2 (Smart Energy) field trials in Cycle 2.</td>
<td>For each use case of LL2, this document provides a detailed description of the field trials executed in cycle 2 and demonstrates the different testbeds, sites and test conditions</td>
</tr>
<tr>
<td><strong>TASKS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2.5 (ex T5.1) - LL planning, setup, operational management and evaluation</td>
<td>Management and monitoring task</td>
<td>Chapter 3 presents the LL2 (Smart Energy) UC setups and architectures in line with the plan reported in D2.4 B (ref. Chapter 4.2)</td>
<td>Provide the overall planning as well as the setup activities for the deployment and testing of the use cases in this LL2</td>
</tr>
<tr>
<td>T5.1 (ex T5.2) - LL2 execution: Smart Energy</td>
<td>LL field trials</td>
<td>Chapter 3 lists the LL2 (Smart Energy) use cases’ field trails and their detailed executions in Cycle 2</td>
<td>For each use case of LL2, this document covers the use case setup, challenges, planned execution, and next steps</td>
</tr>
</tbody>
</table>

2.2 Deliverable Overview and Report Structure

As previously stated, the aim of this deliverable is to report the actual field trials of the Living Lab Smart Energy (LL2) in Cycle 2 (i.e., the second of 3 iterative testing cycles). The starting point of the actual field trials is the results and lessons learned from Cycle 1 (reported in D5.3A) driven by the implementation and testing plan for the operation of LL2, reported in deliverable D2.4A (initial version at M13 – June 2020 – and final version at M28 – September 2021) and D2.4B (submitted on M36 – May 2022), respectively.

This deliverable D5.2B is hence comprised of the following chapters:

**Chapter 3: LL2 field trials Phase 2**

**Chapter 4: Conclusions and Next Actions**

The one chapter describes the field trails of the use cases of LL2 (Smart energy). The following use cases of LL2 are validated in the project through the 5G facility provided by the ICT-17 5G EVE platform with the resulting use case setup status indicated as follows:

- **UC2.1: Industrial Demand Side Management** This use case has been completely designed, partially implemented, and deployed in Cycle 1 (ref. D5.2A) by the Use Case Developer. In Cycle 2, the main architectural components have been revised as described in Section 3.1. Two test cases (TC2.1.1 and TC2.1.3) out of three have been completely integrated as reported in Section 3.1.1. The status of the energy facility, consisting of a Heat Pump remotely controlled by 5G connectivity by the UC Owner (Iren), has been described D5.2A and updated here in Section 3.1.2.1. The status of the 5G facility is set up for RAN coverage and configured to support the communication between the end points in the two test cases TC2.1.1 and TC2.1.3, though due to a temporary unavailability of the 5G EVE platform some functionalities of the 5G facility were not available in Cycle 2 (starting on February 2022) as reported in Section 3.1.2.2. The
deployment of the Vertical Service for two test case planned for Cycle 2 (TC2.1.1 and TC2.1.3) has been completed to run the necessary integration test with two VNF chains: the chain of one VNF (Experiment Server) for the former (TC2.1.1) and two VNFs (Remote Controller and Delay Generator) for the latter (TC2.1.3). The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has been successfully tested in Cycle 1 but has not been trialed in Cycle 2. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the three test cases (TC2.1.1, TC2.1.2 and TC2.1.3), though network KPIs were not collected by the 5G EVE platform, as described in Section 3.1.3 and 3.1.4.

- **UC2.2: Electrical Vehicle (EV) Smart Charging** This use case has been completely designed, implemented, and deployed in Cycle 1 (ref. D5.2A) by the Use Case Developer. In Cycle 2, the main architectural components have been revised as described in Section 3.2. Two test cases (TC2.2.4 and TC2.2.6) out of six have been completely integrated as reported in Section 3.2.1. The status of the energy facility, consisting of an Electric Vehicle Charger (Alfen 22kW AC) integrated with 5G connectivity modem by the UC Owner (Iren), has been revised with respect to D5.2A and updated here in Section 3.2.2.1, since the prototypal innovative Electric Vehicle Charger (JuiceBox 25kW DC) which should have been made available by the Vertical partner (Enel X Way) and installed in the energy facility provided by the UC Owner (Iren) in Cycle 2 is not ready and will be substituted during Cycle three by three Juice2Grid V2G stations (15 kW) integrated with 5G connectivity modem by the Vertical partner of the UC (Enel X Way) by July 2022. The status of the 5G facility represented a critical issue during Cycle 2 due to fact that the 5G coverage that was successfully tested in the energy facility during Cycle 1 (January 2021) was not present at all during Cycle 2 (from June 2022 on). Therefore, though the 5G equipment in the test field is correctly configured to support the 5G communication between the end points in the two test cases TC2.2.4 and TC2.2.6, these test cases have been executed with 4G+ instead of 5G in Cycle 2. Moreover, due to the above-mentioned temporary unavailability of the 5G EVE platform, some functionalities of the 5G facility were not available in Cycle 2 (from February 2022 on) as reported in Section 3.2.2.2. The deployment of the Vertical Service for two test case planned for Cycle 2 (TC2.2.4 and TC2.2.6) has been completed to run the necessary integration test with one VNF chain: the chain of three VNFs (Charge Advisor, Master Control Agent and MQTT Broker) supporting TC2.2.4 and TC2.2.6. The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has been successfully tested in Cycle 1 (TC2.2.3, reported in D5.2A) but has not been trialed in Cycle 2 due to the temporary unavailability of the 5G EVE platform. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the two test cases (TC2.2.4 and TC2.2.6), though network KPIs were not collected by the 5G EVE platform, as described in Section 3.2.3 and 3.2.4.

- **UC2.3: Electricity network frequency stability** This use case has been completely designed, implemented, and deployed in Cycle 2 by the Use Case Developer in line with the preliminary architectural design and the reference control-based conceptual framework reported in D5.2A. The main architectural components have been implemented and deployed as described in Section 3.3. Two test case (TC2.3.1 and TC2.3.2) out of four have been completely integrated as reported in Section 3.3.1. The status of the energy facility integrates the basic facility setup for smart charging in UC2.2 with a frequency regulation meter that will be installed in the facility by the UC Owner (Enel X Way) starting from Cycle 3, instead of Cycle 2 as planned at the begin of the project, as reported in Section 3.3.2. The status of the 5G facility is not completely ready since an extension would be necessary in Cycle 3 for the connectivity between the Vertical Service deployed in the 5G facility and the E-Mobility Platform by the UC Owner. Moreover, the 5G coverage that was successfully tested in the energy facility during Cycle 1 (January 2021) could be not present anymore, as happened to UC 2.2 during Cycle 2 (from June 2022 on). Nonetheless, the test cases TC2.3.1 and TC2.3.2 have been executed in Cycle 2: the former with 4G+, the latter with 5G. Moreover, due to the above-mentioned temporary unavailability of the 5G EVE platform, some functionalities of the 5G facility were not available in Cycle 2 (from February 2022 on) as reported in Section 3.2.2.2. The deployment of the Vertical Service for
the test case 2.3.2 planned for Cycle 2 has been completed to run the necessary integration test with one VNf chain: the chain of four VNfs (Master Control Agent, MQTT Broker and two Local Control Agents) supporting TC2.3.2. The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has not tested yet and is re-planned to Cycle 3 due to the temporary unavailability of the 5G EVE platform. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the test case TC2.3.2, though network KPIs were not collected by the 5G EVE platform, as described in Section 3.3.3.

For each use case, the design, implementation, integration, and deployment in the facility is reported at the end of Cycle 2 as well as the current status of the energy and 5G facilities and the execution of the test cases that have been completely developed so far. The main achievements in terms of development of the Vertical Service (and related Virtual Network Functions supporting the Vertical Service) and distinctive Key Performance Indicators (both from the vertical and the network’s points of view) are described, in reference to Cycle 1.

The key innovation of each use case in LL2 is represented by control and optimization schemes and related algorithms being necessary for the technological and business validation purposes. Ad-hoc control-based algorithms have been therefore designed, implemented, and integrated as vertical oriented virtual network function (VNFs) to yield the Vertical Service to support the use case execution.

For each test case in LL2, the purpose and objective of the tests are explained, and the complete setup is sketched in terms of the energy facility as well as the 5G facility supporting the use case implementation. The main challenges for each test case planned in Cycle 2 are stated. Then planned execution is then detailed and possible effect of the COVID-19 on the progress of the LL2 use cases and mitigation measures are highlighted where occurred. Finally, the next steps of each UC are discussed focusing on Cycle 3 according to the lessons learned during Cycle 2. For the lessons learned and related recommendations in trialing each UC in LL2 we refer to deliverable 5.3B ([19], Section 4).
3 LL2 field trials phase 2

In this chapter, LL2 field trials performed in phase 1 (Cycle 1) are reported as well as all information concerning the development of each use case in LL2. The activities are organized per use case in three sections:

- UC2.1: Industrial Demand Side Management in Section 3.1.
- UC2.2: Electrical Vehicle (EV) Smart Charging in Section 3.2.
- UC2.3: Electricity network frequency stability in Section 3.3.

For each use case, the structure is described as follows:

- **Use case development** including design activities based on the analysis of scenarios and related requirements (from both business and technical point of views) reported in D1.1B, implementation activities in terms of software and hardware components of the architecture developed in the design activities, and integration activities describing the definition, deployment and integration of the VNFs with 5G equipment supporting the use case development with 5G equipment in the 5G facility.
- **Facility setup** including both energy facility and 5G facility to support the use case development in terms of resources made available to realize the use case in an operational environment as closer as possible to vertical related industrial scenarios for reaching a TRL equal to 6 in Cycle 3. As for the use case development, the facility setup activities are in line with the planning and setup activities reported in D2.4B.
- **Execution of the test cases** that have been selected for Cycle 2 according to the plan reported in D2.4B and have been successfully executed in Cycle 2, including purposes and objectives as well as actual versus planned execution, and risks and related mitigation actions undertaken in Cycle 2 and necessary in Cycle 3. For each test cases executed in Cycle 2, the status of integration with other project components (Cross-Domain Service Orchestrator and KPI Visualization System) is reported.

3.1 UC2.1 Industrial Demand Side Management

This section reports the technical design, implementation and integration of UC2.1, namely, “Industrial demand side management”. This section relies on the contribution given in D5.2A and covers the incremental value provided in Cycle 2 with respect to the previous work, reported in Section 3.1 of D5.2A. This value relies on the successful execution of two test cases (TC2.1.1 and TC2.1.3) out of the three planned according to the plan reported in D2.4B.

UC2.1 deals with Demand Side Management (DSM) with a specific focus on the optimal scheduling of energy loads during normal power plant operation, as well as the computation and actuation of flexibilities offered on the dispatching market and the control actions needed to keep the peak power consumption limited. Accordingly, the objective of the use case is to verify that 5G technology can effectively support the development of new grid services and can drastically reduce the tolerance implemented on the meters before disconnection, without having a critical impact on the customer perception as well as on the QoS. From the trials’ point of view, the aim here is to demonstrate that remote controllers (instantiated and distributed at the edge of the 5G network facility) can operate through 5G technology to overcome the problem of blackouts caused by limited time overloads. For related technical and business implications, we refer readers to D1.1A, Section 7.2, and to D1.1B, Section 6.2.

This section is organized as follows. In Section 3.1.1, the main results from the technical design, implementation and integration are reported. In Section 3.1.2 the update of the status of the energy facility, consisting of a Heat Pump remotely controlled by 5G connectivity by the UC Owner (Iren), and the update of the status of the 5G facility (5G EVE) is reported in Sections 3.1.2.1 and 3.1.2.2, respectively. The executions of the test cases TC2.1.1 and TC2.1.3 with 5G are reported in Sections 3.1.3 and 3.1.4, respectively, in terms of purpose, test setup, challenges and plan, including the VFN chain set up, the integration with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) and the 5G-Solutions KPI Visualization System (KPI-VS).
For the development of the use case, one pilot has been identified by UC Owner (Iren). It is a building belonging to the Municipality of Turin and operated by Iren. The facility is equipped with energy systems according to the setup activity reported in D5.2A (see Section 3.1.2).

The steps to develop this use case are divided into the following test cases:

- **TC2.1.1: Heat Pump’s Remote Monitoring and Control Unit (RMCU) communication to the Aggregator** with the aim of evaluating the pros/cons of a 5G communication (compared to 4G) in terms of reliability, flexibility and speed/latency when pushing consumptions data and/or receiving flexibility inputs from the Aggregator or, at local level, from the Building Management System (BMS).

- **TC2.1.2: Electrical monitoring and comfort monitoring devices data pushing** with the aim of evaluating the pros/cons of a 5G communication (compared to 4G) in terms of reliability, flexibility and speed/latency when pushing consumption data to the BMS and/or RMCU Supervision platform. Post fiscal electrical meters could be installed on the main electrical loads of the building (Heat Pump, lighting, elevators, etc.). Comfort monitoring sensors could have a local wireless communication to a concentrator embedded with 5G.

- **TC2.1.3: Load shedding for overload avoidance** with the aim of evaluating the pros/cons of a 5G communication (compared to 4G) for latency when applying for load disconnection to avoid blackout. The objective is to compare the time needed to detect a power peak and to react by applying prioritized load disconnection when using 4G versus 5G connections among the controller and the plant (not considering the time needed by the controller to evaluate a feasible solution) in different scenarios (controller hosted in a cloud environment versus 5G edge server).

In line with the test case planning reported in D2.4A, TC2.1.3 has been executed in Cycle 1 and has been revised for 5G aspects in Cycle 2 as reported in the following Section 3.1.4. TC2.1.1 and TC2.1.2 have been designed, implemented and integrated in Cycle 2 as described in the following Section 3.1.3, where the execution of TC2.1.1 is reported while TC2.1.2 is planned for Cycle 3.

3.1.1 Use Case Technical Design, Implementation and Integration

This section describes the advancements in the technical design, implementation and integration achieved in Cycle 2. The section relies on the consolidated contribution reported in D5.2A (Section 3.1.1) and reports here the incremental contribution given in Cycle 2. We recall here Figures 28, 29 and 30 of D2.4A (that have been reported in the figure below as A, B and C, respectively), the high-level architecture (A) has been specialized and refined to cope with TC2.1.1 and TC2.1.2 (B) and TC2.1.3 (C) in Figure 1.
In the context of UC2.1 test cases, the following main architectural elements can be identified:

1) **Remote Control Unit (RMCU)** - it is a micro-controller in charge of measuring data and actuating commands, it is connected to field equipment.

2) **Remote Terminal Unit (RTU)** - it is connected to one or more RMCUs, it is in charge of collecting data from and of sending commands to the controlled RMCUs. It is used to communicate with grid’s Transmission System Operators (TSOs) and accessing the Italian Energy and Power market.

3) **Local Control Agent** – it is a software control agent operating on top of the RMCU, it operates simple local decisions.

4) **Master Control Agent** - it is a software control agent operating on top of the RTU, it operates global decisions.

During Cycle 2, TC2.1.1 and TC 2.1.3 have been selected to be executed. In the context of TC2.1.1, the specialized reference architecture (letter B of the above figure) has been further refined to derive technical design specifications ready for an actual (software) implementation and integration (on the field).

![Figure 2 Reference architecture specialized for TC2.1.1](image)

TC2.1.1 deployment architecture is depicted in the Figure 3 below. In TC2.1.1, the system under control is a commercial Heat Pump, whose sensors and actuators are connected to a proprietary PIC and, via Modbus, to the Sensors Gateway (an AiLux UPMC, acting as a RMCU). The sensors gateway data are aggregated and stored in a MySQL server hosted in a Monitoring server (an AiLux 5G-enabled UPMC, acting as BMS/RTU). The Control Service Provider (CSP) has a Local Control Agent that pairs which each BMS/RTU and a Master Control Agent that controls all the Local Control Agents. From a deployment point of view, the CSP has been deployed as an Experiment Server that hosts both the Local Control Agent and the Master Control Agent (that actuates the Heat Pump remote control and interacts with the 5GS KPI Visualization System).
The TC 2.1.1 deployment architecture reported in the figure above, is referred to the Cycle 2. The architecture is an evolution of the one from Cycle 1. In particular, the main architectural change is the direct 5G connection between the on-field sensors gateway (the AiLux UPMCs) with the CSP local control agent hosted by the Experiment Server located in the MEC (Multi Access Edge Computing).

Table 2 Federated MySql Table ‘comandi’

<table>
<thead>
<tr>
<th>ID</th>
<th>NOME</th>
<th>VALORE</th>
<th>DATA_ESECUZIONE</th>
<th>DATA_RICHIESTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OUT0</td>
<td>1</td>
<td>2020-07-03 09:04:03</td>
<td>2020-07-03 08:59:14</td>
</tr>
<tr>
<td>2</td>
<td>OUT0</td>
<td>0</td>
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<td>2020-07-03 08:59:58</td>
</tr>
<tr>
<td>3</td>
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<td>0</td>
<td>2020-07-03 09:05:11</td>
<td>2020-07-03 09:01:23</td>
</tr>
<tr>
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<td>2020-07-03 09:09:43</td>
</tr>
<tr>
<td>5</td>
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<td>100000</td>
<td>2020-07-03 09:16:46</td>
<td>2020-07-03 09:10:37</td>
</tr>
<tr>
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<td>150000</td>
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<td>2020-07-03 09:13:33</td>
</tr>
<tr>
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<td>60000</td>
<td>2020-07-03 09:19:03</td>
<td>2020-07-03 09:14:50</td>
</tr>
<tr>
<td>8</td>
<td>RO035</td>
<td>30000</td>
<td>2020-07-03 09:19:39</td>
<td>2020-07-03 09:15:37</td>
</tr>
<tr>
<td>9</td>
<td>RO034</td>
<td>20000</td>
<td>2020-07-03 09:20:46</td>
<td>2020-07-03 09:16:55</td>
</tr>
<tr>
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<td>RO033</td>
<td>40000</td>
<td>2020-07-03 09:21:20</td>
<td>2020-07-03 09:17:07</td>
</tr>
</tbody>
</table>

With this architectural change, we avoided passing through any interaction with external back-end servers when executing the control loop. Even if the time constraints related to the heat-pump dynamics are relatively slow (minutes) if compared with the 5G latency performances, in this test case the main advantage of using 5G relies on:

- the use of a proxy 5G MEC, that offloads a standard centralized cloud-based architecture;
- the high device density guaranteed by 5G technologies, considering that the number of on-field sensors gateways is expected to grow fast in the next years.
Table 2 and Table 3 show some example-records collected in the UPMC tables ‘comandi’ (commands) and ‘misure_periodiche’ (periodic measures) in detail. Precisely, the table ‘misure_periodiche’ registers the queries regarding the commands given by the Experiment Server to the UPMC device. Finally, the table ‘misure_periodiche’ shows the records registered by the Monitoring Server regarding the sensors’ status of the Heat Pump.

<table>
<thead>
<tr>
<th>ID_MIS</th>
<th>SN</th>
<th>IDX_DEV</th>
<th>UNIX_TIME</th>
<th>PC_TIME</th>
<th>N_CAMP</th>
<th>R0001</th>
<th>R0002</th>
<th>R0003</th>
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<tr>
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<td>0.000</td>
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<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
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<td>19063</td>
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<td>1605630218</td>
<td>0</td>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>9</td>
<td>19063</td>
<td>0</td>
<td>1605630450</td>
<td>1605630250</td>
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<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>10</td>
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<td>0</td>
<td>1605630480</td>
<td>1605630250</td>
<td>0</td>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The procedure of the instantiation in the 5G EVE facility involves the configuration and uploading of some configuration files as blueprints and descriptors. Alongside to this procedure a VNF package (this.tar.gz file describes the network service which points the image of the VM) must be sent to the Site Manager who uploads the file in the VNF repository of the facility. As in TC2.1.3, for TC2.1.1, the following blueprints/descriptors were prepared according to the deployment framework and related guidelines from the 5G EVE project: VSB, VSB NSD, EXP NSD, CTX, and CTX NSD. Even though no execution is planned for Cycle 1, CTX and CTX NSD have been already defined and uploaded in the portal. These files allow the user to simulate different networking backgrounds during the experiment activations. TC2.1.1 is configured with VNF, VL, CP, and SAP. Figure 4 shows the structure of the VSB for UC2.1 in reference to TC2.1.1 from the 5G EVE portal.
The CTX and CTX NSD of the “Delay Generator” have been chosen and the related JSON files have been configured with suitable parameters. In particular, Figure 5 below shows that the CB components, which are as follows:

1. Atomical functional components VNF:
   a. Delay_generator
2. VL:
   a. vl\_dg\_out
   b. vl\_dg\_in
   c. vl\_dg\_mgmt
3. CP:
   a. cp\_dg\_ext\_out,
   b. cp\_dg\_in,
   c. cp\_dg\_mgmt,
4. SAP:
   a. sap\_dg\_in,
   b. sap\_dg\_out,
   c. sap\_dg\_mgmt

![Figure 5 UC2.1 Context Blueprint for TC2.1.1](image)

Afterwards, the descriptors of the vertical and experiment server must be configured (i.e., VSB NSD and EXP NSD). Finally, the Exp NSD defines a specific experiment for the 5G EVE platform.

In conclusion, the experiment must be scheduled from the Use Case Developer (Ares2t), in the “Request Experiments” section and accepted by the Site Manager (TIM). At this stage, the VNF is ready to be instantiated in the portal in “Manage Experiment” section and consequently the experimenter can execute the experiment.

For TC2.1.1, there are two types of KPIs, namely, vertical service KPI and Network KPIs. These can be summarized in the following Table 4.

### Table 4 List of Vertical Service and Network KPIs for UC2.1.1

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuation Time</td>
<td>Vertical Service</td>
<td>s</td>
</tr>
<tr>
<td>Latency Userplane RTT</td>
<td>Network</td>
<td>ms</td>
</tr>
<tr>
<td>Availability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>Reliability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>User Data Rate Downlink</td>
<td>Network</td>
<td>Mbps</td>
</tr>
<tr>
<td>User Data Rate Uplink</td>
<td>Network</td>
<td>Mbps</td>
</tr>
</tbody>
</table>

Note that only the first one is generated by the VNF of the Remote Controller. The others are generated by the 5G EVE facility during the experiment activation.

1. **Actuation Time**: Round-Trip-time needed to commit the db query regarding the command to actuate
2. **Latency User Plane RTT**: Round Trip Time experienced by the VNF deployed between sending the request to the 5G EVE facility component and receiving a response.
3. **Availability**: amount of uptime in a network system over a specific time interval. Uptime refers to the amount of time a network is fully operational.
4. **Reliability**: Percentage of assurance that the delivery of data to intended recipients was successful.

5. **User Data Rate Downlink**: it is basically the rate at which data is transferred from the 5G EVE portal to the end user in a time interval of 5 seconds.

6. **User Data Rate Uplink**: it is basically the rate at which data is transferred from the end user to the 5G EVE portal in a time interval of 5 seconds.

Finally, Table 5 shows the list of APIs to the 5G-Solutions KPI Visualization System (KPI-VS). The TC2.1.1 utilizes the APIs exposed by 5G-Solutions KPI-VS through the VNF Experiment Server. In particular the “Start Notification” interface is responsible for creating a unique session for each test case execution activated on the 5G-Solutions KPI-VS side. This is the first request sent by the VNF Experiment Server to KPI-VS. Consequently, the same VNF starts sending the Vertical Service KPIs through “Vertical Service KPI sending” API. All indicators are collected by the KPI-VS which make them visualizable in real time. At the end of the experiment, a “Stop Notification” is sent to KPI-VS. The Start/Stop Notifications are not only responsible to create/terminate the experiment but to also provide a unique experiment ID to the KPI-VS which then uses this ID to retrieve and filter all Network KPIs from the 5G EVE facility. The VNF Experiment Server has been deployed in the VNF chain completed of these APIs though they will be tested for Cycle 2. The reference implementation of the above-mentioned interfaces can be found in [10].

<table>
<thead>
<tr>
<th>Name</th>
<th>Interface</th>
<th>Method</th>
<th>URI</th>
<th>KPIs associated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Notification</td>
<td>POST</td>
<td></td>
<td><a href="https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>All Network KPIs (Latency UserPlane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
<tr>
<td>Stop Notification</td>
<td>POST</td>
<td></td>
<td><a href="https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>All Network KPIs (Latency UserPlane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
<tr>
<td>Vertical Service KPI sending</td>
<td>POST</td>
<td></td>
<td><a href="https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>Vertical Service KPI (to be determined)</td>
</tr>
</tbody>
</table>

In the context of TC2.1.3, the specialized reference architecture (letter C of the above figure) has been further refined to derive technical design specifications ready for an actual (software) implementation and integration (on the field).
Figure 6 LL2 reference architecture specialized for TC2.1.3

As shown in Figure 6 for TC2.1.3, the Local Control Agent and the RMCU have been designed to be a **Proof-of-Concept (PoC)** to be developed by Ares2t and, in the following, we will refer to it as the **Local Controller**. The Local Controller (i.e., the PoC) interfaces with the field sensors (e.g., power meters) and field actuators (e.g., power switches) by means of an integrated RMCU (that is the hardware part of the PoC) that is controlled locally by a Local Control Agent (that is the software part of the PoC). The **Remote Controller** is in charge of controlling remotely one or more Local Controllers by means of reliable and low latency 5G communications. The Remote Controller is composed by a Remote aggregator and a Master Control Agent. The former is in charge of collecting the Measurements provided by the Local Controllers and to feedback them with the needed corrective Actions to apply for load shedding; the latter is in charge of elaborating proper load shedding algorithms that find the best disconnection/reconnection strategy.

The designed architecture (shown in the above Figure 6) has been elaborated to cope with development and deployments details, as shown in the Figure 7 below.

Figure 7 Deployment architecture for TC2.1.3
The architecture reported in the figure above is referred to the Cycle 2. This architecture is an evolution of the one proposed and implemented in Cycle 1. In particular, the main architectural change is the substitution of a 5G mobile phone (acting as a 5G to Wi-Fi hot-spot) with a dedicated 5G modem-router (equipped with both gigabit ethernet and Wi-Fi 6 connectivity). We decided to apply this architectural change to avoid any potential network latency due to the usage of software-based hotspot functionality embedded in the Android mobile phone.

In the Figure 7, the following deployment elements can be identified:

1. Local Controller
2. Remote Controller
3. Delay Generator

The Local Controller (i.e., the PoC) can be used to perform tests in an indoor scenario, located in the target area selected for the 5G test field in the City of Turin (Via Francesco De Sanctis, 12, see Section 3.1.2.1). Since the PoC is a portable system, it can be used to perform dedicated tests also in other 5G sites in the reference ICT facility.

The Local Controller connects to the 5G EVE infrastructure by means of a 5G mobile terminal that communicates with the Local Controller via a dedicated 5G modem-router. Once connected to the 5G radio access network (RAN), the Local Controller interacts with the Remote Controller sending both periodic and event-based updates on the status of the system monitored by the Local Controller. Each event causing the intervention of the load shedding algorithm allows to collect statistics and to calculate the KPI values that are sent to the 5G-Solutions KPI visualization server (KPI-VS). Furthermore, the Remote Controller and Local Controller provide both a web-based Graphic User Interface (GUI) to monitor the status of the overall system as well as of any controlled equipment.

The Local Controller is the core of the smart building environment. It is in charge of connecting to the devices, providing a user GUI, storing data about the system and managing the communication with the Remote Controller. The Local Controller must be connected to a Wi-Fi or Local Area Network (LAN) connection through an Ethernet router and modem. The sensors required for energy monitoring are power meters as they measure the current absorbed by an electric load and consequently the active power being absorbed. The actuators are switches which close the circuit, depending on the command received. The WLAN (Wireless Local Area Network) connects the devices and the Local Controller and is based on the Message Queuing Telemetry Transport (MQTT) protocol over a Wi-Fi/Ethernet network.
To implement all the features of a real setup, in Cycle 1 Ares2t designed and realized a portable PoC, which is the representation in scale of a residential building. It includes a series of sockets connected to sensors and actuators with hardware and software Local Controllers. As in real environments, the user can interact only with the frontal panel and the controller software GUI. The first step for PoC realization was the selection of commercial, low-cost, easy-to-install and off-the-shelf equipment, including wireless switches and power meters. It is decided to use the Shelly devices produced by Allterco Robotics through the EU’s operational program Innovation and Competitiveness. The products selected are the following: Shelly 1, Shelly 4PRO and Shelly EM. Once designed and realized, the PoC is certified for the safety standards by a 3rd party on behalf of the Use Case Developer.

The portable PoC architecture depicted in the figure above is referred to the Cycle 2. The Cycle 2 architecture is an evolution of the Cycle 1 architecture. In particular, to boost the sensing and actuation performances we decided to substitute the 2 Shelly 1PM and the 2 Shelly Plug S with a Shelly 4PRO. Indeed, the Shelly 4PRO supports 4 mono-phase lines (up to 10A) and uses an ethernet cable to connect to the Raspberry Pi, while Shelly 1PM and Shelly Plug S use a Wi-Fi connection.
The Local Controller hardware consists of a Raspberry Pi (RPi) 4 with 4GB RAM and 64 GB memory storage. The software installed is free and opensource. It is based on the Hass.io operating system that transforms the Raspberry into full IoT Hub, optimized to run Home Assistant (HA). HA is a service written in Python to control all the IoT devices connected to the Local Controller. HA provides a GUI to interact with the system, on a web page reachable by the IP address of the Local Controller. In HA, the following third-party services are installed:

1. Data storage, analysis and visualization: InfluxDb, MariaDB and Grafana.
2. Remote Controller communication: Node-RED.
4. MQTT protocol implementation (Mosquitto broker).

The Remote Controller is the other main block which is referred in the architecture in Figure 7. The implementation of the Vertical Service is conducted via the development of the Remote Controller in the Virtual Machine (VM) in the OpenStack environment (see Core Network in Figure 3.). TC2.1.3 vertical service was developed in the VM in the OpenStack hosted by the 5G EVE platform.

The architecture of the Remote Controller is based on a virtualized docker environment in which the container for HA, Grafana, InfluxDB, and Node-RED are installed. Every container has its own volumes where the configuration files are stored. Each service that is needed outside of the virtualized ambient is rooted by docker to the external network passing through the firewall. For the ease of installation of the controller, the construction of this structure is created via a docker-compose file. In the Remote Controller, Node-RED takes care of all the operations, e.g., it communicates with the Local Controller via HTTPS, executes the algorithm, elaborates the response, stores the Local Controller data and the KPI data in InfluxDB, enacts a congestion control, and communicates with the KPI server. The AH creates a graphical interface in which all the services can be accessed and in Grafana and it is also possible to see all the data stored in InfluxDB. Besides, each dashboard for each Local Controller is automatically created by Node-RED. All the services in the Remote Controller are optimized for low-latency operation.
Once the vertical service development is completed, the integration phase takes place, and this involves the onboarding of the VNF. Once the design of the vertical service is completed, the procedure of the instantiation in 5G EVE platform gets started. A set of procedures must take place as:

1. Definition of the network interfaces in the VM, installation of python2 (necessary package to allow the Runtime Configurator to work during the 5G experiment execution), and snapshot of the VM.
2. The VNF package (this tar.gz file describes the Network Service (NS) and points the image of the VM) must be sent to the Site Manager who uploads the file in the VNF repository of the facility.
3. Design and upload of the blueprints/descriptors in the portal of the 5G EVE facility.

As done in Cycle 1, the following blueprints and network service descriptors (NSDs) are prepared:

1. Vertical Service Blueprint (VSB).
2. Vertical Service Descriptor (VSB NSD).
3. Context Blueprint (CTX).
5. Test Case Blueprint (TCB).
6. Experiment Descriptor (EXP NSD).

In this section we do not report the deployment of the Vertical Service in the 5G EVE platform since it is quite similar to Cycle 1. We refer to D5.2A (Section 3.1.1) for the complete description of the Vertical Service in the 5G EVE platform. In what follows we report:

- the structure of the VSB for TC2.1.3 from the 5G EVE portal at the end of the deployment
D5.2 - D5.2B: LL field trials (phase 2)

Figure 11 Vertical Service Blueprint for TC2.1.3

- the structure of the CTX for TC2.1.3 from the 5G EVE portal at the end of the deployment

Figure 12 UC2.1 Context Blueprint for TC2.1.3

- the step-by-step CDSO Implementation for TC2.1.3 as in Cycle 1

Table 6 CDSO Implementation for TC2.1.3

<table>
<thead>
<tr>
<th>Step</th>
<th>Interface with</th>
<th>API</th>
<th>Parameters</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Login</td>
<td>5GEve-Portal Login</td>
<td>TCP</td>
<td>Account credentials</td>
</tr>
<tr>
<td>1.2</td>
<td>Present Experiments to select from</td>
<td>5GEve-Portal API</td>
<td>TCP</td>
<td>Token</td>
</tr>
</tbody>
</table>
- the Vertical Service KPIs and network KPIs for TC2.1.3 as in Cycle 1

Table 7 Reference KPIs for TC2.1.3 in Cycle 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disconnection Time</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Latency Userplane RTT</td>
<td>Network</td>
<td>ms</td>
</tr>
<tr>
<td>Availability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>Reliability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>User Data Rate Downlink</td>
<td>Network</td>
<td>Mbps</td>
</tr>
<tr>
<td>User Data Rate Uplink</td>
<td>Network</td>
<td>Mbps</td>
</tr>
</tbody>
</table>

Note that only the first one is generated by the VNF of the Remote Controller. The others are generated by the 5G EVE facility during the experiment activation.

1. **Disconnection Time**: This KPI shows the aggregate of 4 measurements:
   a. Sensor update time: time interval needed to update the consumption sample.
   b. Data processing time: time interval needed by the Local Controller to perform some data processing.
   c. Remote Controller Round Trip Time (RTT): Round Trip Time experienced by the Local Controller between sending the request to the Remote Controller and receiving a response.
   d. Actuation time: time interval needed by the Local Controller to actuate the command.

2. **Latency User Plane RTT**: Round Trip Time experienced by the VNF deployed between sending the request to the 5G EVE facility component and receiving a response.

3. **Availability**: amount of uptime in a network system over a specific time interval. Uptime refers to the amount of time a network is fully operational.

4. **Reliability**: Percentage of assurance that the delivery of data to intended recipients was successful.

5. **User Data Rate Downlink**: it is basically the rate at which data is transferred from the 5G EVE portal to the end user in a time interval of 5 seconds.

6. **User Data Rate Uplink**: it is basically the rate at which data is transferred from the end user to the 5G EVE portal in a time interval of 5 seconds.
- the set of APIs to the 5G-Solutions KPI-VS (for the reference implementation, we refer to [10] and [20])

<table>
<thead>
<tr>
<th>Name</th>
<th>Interface</th>
<th>Method</th>
<th>URI</th>
<th>KPIs associated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Notification</td>
<td>POST</td>
<td></td>
<td><a href="https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>All Network KPIs (Latency Userplane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
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</tr>
<tr>
<td>Vertical Service KPI sending</td>
<td>POST</td>
<td></td>
<td><a href="https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>Vertical Service KPI (Disconnection Time)</td>
</tr>
</tbody>
</table>

Table 8 API list to the KPI-VS for TC2.1.3 in Cycle 1

3.1.2 Overview of the Test Setup According to the Plan

In this section, the setup activities concerning the energy and the 5G experimental facility are detailed for Cycle 2, while for those related to Cycle 1 we refer to D5.2A (Section 3.1.2). The two facilities have been designed and implemented specifically to support the use case development reported in Section 3.1.1.

3.1.2.1 Energy facility setup

The energy facility made available by the UC Owner (Iren) consists of the direct control of the HVAC system and appliances in one of the several buildings managed by Iren as a facility manager in the City of Turin. The concept is to enhance the energy flexibility of eligible loads of the building to provide grid services (e.g., demand side management, demand response). Those loads were individuated in the electrical driven Heat Pump used for providing space heating or cooling and producing Domestic Hot Water and a cluster of smart plugs that can be connected to several appliances. The building and the requirements in terms of consumptions are thermal energy for space heating, Domestic Hot Water production and space cooling, and electricity for appliances and auxiliaries have been completely reported in D5.2A (Section 3.1.2.1). During Cycle 2 the connectivity with 5G equipment to connect the end point to the 5G facility and to the Vertical Service has been deployed and tested in both test cases (TC2.1.1 and TC2.1.3). Moreover, an integration of the Building Automation and Control System has been undertaken in order to extend the number of sensors used to define control logics. For instance, sensors detecting air temperature and humidity might be used to ensure the respect of the comfort constraints. Next steps planned for Cycle 3 are the execution of TC2.1.1, TC 2.1.2 and TC2.1.3 on field tests.

3.1.2.2 5G facility setup

As reported in D5.2A, the building that hosts UC2.1 was not originally covered by the ICT-17 5G EVE facility. As the energy facility was identified by the UC Owner (Iren) in Q4/2019 (before the LL2 official starting date) the Site Manager (TIM) of the Italian Site of the 5G EVE facility provided a preliminary technical confirmation of the commitment from the site manager to extend the above-mentioned facility to cover the energy facility hosting UC2.1 in Q2/2020. In Cycle 1, the extension of the 5G EVE facility has been tested in the specific area (please
D5.2 - D5.2B: LL field trials (phase 2)

refer to D5.2A, Section 3.1.2.2). In Cycle 2 the test cases TC2.1.1 and TC2.1.3 have been successfully executed with 5G, as reported in the following Section 3.1.3 and 3.1.4, respectively. In Cycle 3 the TC2.1.1, 2.1.2 and 2.1.3 are planned to be trialed in the test field.

Though the physical infrastructure of the 5G EVE facility was setup and available, the 5G EVE platform supporting the Use Case 2.1 was not fully operating from February 2022 on. As a consequence, the 5G EVE web portal was not reached and during the execution of test cases TC2.1.1 and TC2.1.3 there was no mean:

1) to dynamically deploy the necessary VNF chain
2) to schedule any test case execution
3) to integrate the 5G-Solutions CDSO via 5G EVE north-bound APIs
4) to communicate Network KPIs to the KPI Visualization System

For this reason, in the execution of test cases reported in the following,

1) the VNF chain has been deployed manually,
2) there was no schedule through the 5G EVE web portal,
3) there was no trial with CDSO
4) it was not possible to collect the Network KPIs by the KPI Visualization System.

3.1.3 Execution of Test Case TC2.1.1

3.1.3.1 Purpose of the Test

From now on, we describe the setup and execution of TC2.1.1 Heat Pump’s Remote Monitoring and Control Unit (RMCU) communication to the Aggregator. This test case focuses on the integration in the Virtual Power Plant (VPP) by sending dispatching orders to the Heat Pump. The main purpose of the test is to exploit the 5G MEC architectural component to offload the legacy, cloud-based back-ends.

3.1.3.2 Test Setup

The setup activities for the execution of TC2.1.1 have been performed in Iren’s premise located in the City of Turin as reported in Section 3.1.2.1. They included the full realization of the deployment architecture depicted in Figure 7.

3.1.3.3 Challenges

The main objective of this experiment is to investigate the possibility of using 5G technology to remotely control Heat Pump’s Control Unit. In this regard, 5G architecture is more relevant than its high reliability, high device density, low-latency and high-speed performances. Indeed, the time constraints related to the heat-pump dynamics are really slow (minutes) if compared with the 5G latency performances (milliseconds). In this test case, the main advantage of using 5G relies on the use of a proxy 5G MEC, that offloads a legacy, centralized, cloud-based back-ends, and on the high device density guaranteeing adequate performances in case of high-density Control Units in one squared kilometer. Setting up local controllers in the 5G MEC components, enables an edge-computing paradigm that on the one hand cuts the amount of data sent to the cloud back-end and the other hand pave the way of new business opportunities related to the use of VNFs dedicated to the purpose of remotely control numbers of control units (not only limited to Heat Pumps).

3.1.3.4 Planned Execution

The execution of TC2.1.1 has been trialed with 5G in Cycle 2, in line with the planned execution (reported in D2.4B).
3.1.4 **Execution of Test Case TC2.1.3**

From now on, we describe the setup and execution of TC2.1.3 Load shedding for overload avoidance. This test case has been introduced, described, and trialed in Cycle 1 (please refer to D5.2A, Section 3.1.3). The execution steps have been reported in D5.3A (Section 4.1.3).

3.1.4.1 **Purpose of the Test**

TC2.1.3 aims to test a 5G-based load shedding architecture for overload avoidance. This test is based on the consideration that load management in non-residential buildings requires the capability to apply for a rapid load shedding to avoid local overloads and related blackouts due to the operator’s intervention. In particular, if a suitable load shedding strategy is applied in the interval before the occurrence of an overload and the consequent blackout, the power failure (and its consequences) can be avoided. In a scenario of interconnected non-residential buildings, it makes sense to have an edge service dedicated to remotely control the local electric control systems that relies on custom or commercial building automation systems. In such a scenario, the network latency is essential to guarantee a rapid load shedding.

In the scenario covered by the test case on load shedding for overload avoidance, the control loop duration (that, hereafter we will refer to as the “response_time”) is composed by several time elements:

1. The time needed by the sensors to estimate the energy consumption of a load.
2. The time needed to process the data.
3. The time needed to send the data.
4. The time needed to actuate a command.

Network latency is an important aspect that, depending on the sensor and actuation technologies, can weigh up to 25% to the control loop. The main challenge of this test case is to demonstrate that remote controllers (instantiated at the edge of the network facility) can operate through 5G technology so as to overcome the problem of blackouts caused by limited time overloads. In particular, we want to measure the improvement with respect to the actual remotization and virtualization techniques that make use of 4G connection and cloud environments.

3.1.4.2 **Test Setup**

The setup activities for the execution of TC2.1.3 relies on preliminary 5G connectivity pre-trial test with a 5G user equipment (namely, a 5G mobile phone as shown in Figure 13) in Iren’s premise located in the City of Turin instead of the testbed selected for the use case. This setting was due to the possibility of completing the integration with the 5G facility in a lab environment, being more suitable to run different executions to identify integration issues with respect to the operative testbed, that is going to host the final test case execution.
Then, the test case setup in Iren’s premise has been performed in line to the integration activities described in Section 3.1.1 for TC2.1.3 and according to the planned execution.

The actual setup involved all the hardware and software components described in the architecture detailed in Section 3.1.1 (see Figure 7) and reported in the following:

- **Local Controller (PoC)** with the unit HA server (see Figure 15).
- Huawei CPE Pro 5G modem-router (see Figure 14).
- Laptop connected to the 5G modem running the **Home Assistant Web Interface** through web browser (i.e., Google Chrome) (see Figure 16).
- **Cross-Domain Service Orchestrator** CDSO integrated with the facility 5G EVE (not present in Cycle 2)
- The full VNF chain deployed (manually)
  - Delay Generator as VNF deployed on the facility 5G EVE and integrated in the VNF chain configured by the Vertical Service.
Remote Controller as VNF deployed on the facility 5G EVE and integrated in the VNF chain configured by the Vertical Service.

- **5G-Solutions KPI-VS** through the suitable interfaces defined in the use case implementation and integration activities (please see Section 3.1.1 and [4]).

All components have been individually trialed during different sections of test case execution before the test case setup.

![Figure 15 PoC Set up for TC2.1.3](image)

For a complete description of the trial execution after the setup of the above-mentioned components, we refer to D5.3A (see [3], Section 4.1.3). Basically, once the Local Controller is on, this needs to be connected to 5G EVE network through a dedicated 5G SIM card hosted in the 5G modem-router (see Figure 14). Meanwhile, a third device (laptop) needs to be connected to the same network to access to the HA client hosted in the Local Controller (see Figure 16).

![Figure 16 HA client hosted in the Local Controller (PoC) for TC2.1.3](image)

Once the connectivity is established, all the devices are turned on in the Local Controller and a load (a coffee machine as shown in Figure 17 or a hair dryer depending on the test case execution) is plugged to the Local
Controller, the Experimenter is ready to start the communication between the VNF Remote Controller and the Local Controller and simultaneously the CDSO activates the experiment on the 5G EVE facility side.

![Figure 17 One of the loads in the execution of the test case in TC2.1.3](image)

### 3.1.4.3 Challenges

The main objective of this experiment is to investigate the possibility of using 5G technology to remotely control the load management of smart buildings. In this regard, low-latency and high speed could be real benefits in power monitoring and control at all the nodes in the distribution grid. In this case, the aim here is to investigate the potential of a 5G network driven by multi-access edge computing (MEC) and low-latency communications and compare it to other types of communications commercially available such as 4G, fiber optic and cloud infrastructures. Tests performed had the main objective to demonstrate the efficiency of the system and evaluate the impact of the 5G network in the control architecture. The main KPI used was the ‘disconnection_time’. This value was used to measure the rapidity (in milliseconds) of the Remote Controller to perform the load disconnection in the Local Controller as the power peak is applied to it. The ‘disconnection_time’ includes the delay introduced by the 5G connection, controllers processing and field devices.

As explained in Figure 18, the measurement process starts from the ‘consumption sensor’, which measures the whole ‘consumption’ of the building. The first measurement is obtained by the difference in time of the arrive timestamps of two ‘consumption’ samples that is called ‘Sensor update time’, which is then added to the ‘Data processing time’, and to the ‘Remote Controller RTT’. The latter, i.e., RTT, is the time which passes from the starting of a request to the Remote Controller and the arrival of the response. Finally, the whole value is added to the ‘Actuation time’, given by the difference between the arrive timestamp of the actuation commands from the Remote Controller and the arrival timestamp of the last acknowledge message (ACK) sent by the devices. The final output is the ‘Disconnection time’, which shows the system performances.
3.1.4.4 Planned Execution

According to the GANTT chart and the test plan reported in D2.4B, the execution of Test Case 2.1.3 was planned and tested successfully in Cycle 1. During the trial activities, a few issues were experienced. Some of them have been completely solved in Cycle 1 (e.g., the integration between the 5G-Solutions KPI Visualization System and 5G EVE platform for collecting Network KPIs), others were related to the 5G end to end connectivity in testing the Vertical Service indoor. The Test Case 2.1.3 has been re-planned in Cycle 2 so that all the recommendations from Cycle 1 could be considered and actuated.

3.1.5 Effect of the COVID

COVID pandemic situation affected UC2.1 setup and execution in trials of the first part of Cycle 2. Nevertheless, as described above, the partners collaborated in the integration and deployment activities to set up the test case execution and the test cases planned for Cycle 2 (TC 2.1.1 and 2.1.3) have been successfully executed with 5G according to the plan.

3.1.6 Mitigation Measures

Mitigation measures from Cycle 1 have been considered in Cycle 2 and no update has been necessary since the test cases planned for Cycle 2 (TC 2.1.1 and 2.1.3) have been successfully executed with 5G according to the plan.

3.1.7 Next Steps

Through the experience in trialing TC2.1.1 and 2.1.3, we gained a lot of information to support the development of TC 2.1.2 planned for Cycle 3 and to improve the Vertical Service KPIs in terms of overall test performance in Cycle 3, where the execution of all test cases (TC 2.1.1, 2.1.2 and 2.1.3) is planned.

3.2 UC2.2 Electric Vehicle Smart Charging

This section reports the technical design, implementation and integration of UC2.2. The contribution relies on the one given in D5.2A and covers the incremental value provided in Cycle 2 with respect to the previous work, reported in Section 3.1 of D5.2A. This value relies on the execution of two test cases (TC2.2.4 and TC2.2.6) in 4G+ for the reasons being explained in the following section, out of the six test cases according to the plan reported in D2.4B.
The use case focuses on the development of a 5G Vertical Service dedicated to the optimization of the distributed smart charging process in industrially relevant scenario, as it leverages 5G communications to enable the decentralized real time control of the EVs charging power according to boundary conditions established by the drivers and grid players. Specifically, as reported in D1.1B, the problem is the one of computing and actuating, in real-time, the charging power setpoints for active EV charging sessions taking place in a given load-area, in order to enable the control of the aggregated load and, at the same time, to ensure that the drivers preferences on final state-of-charge (SoC) and on dwelling time are matched. Decentralization is used in order to distribute the computational effort among communicating session agents (Local Control Agents); as decentralization implies multiple interactions among such distributed agents, the low latency of 5G technology is here considered the enabling factor.

Figure 19 UC2.2 – Reference architecture

All UC testing activities leverage the 5G EVE infrastructure and the Energy facility identified by the UC Owner (IREN) in the City of Turin. As described in the following, the development of the E2E use case requires interventions at different levels, including the design and implementation of a decentralized controller, the update of the vertical energy infrastructure, the setup of the 5G facility, and the integration among them. Keeping in mind the target E2E use case, the reference architecture (see Figure 19) and the related validation plan have been established in D2.4B, by which the list of test cases, previously introduced in D5.2A, have been re-defined, to incrementally validate the architecture components and interfaces as soon as they are made available. The test cases and the rationale at their basis are described in D2.4B and are here briefly summarized in terms of key objectives to make the reading of what follows easier.
• **TC2.2.1:** CPO Back-End integration in 5G facility to test the communication between the E-Mobility Platform (CPO back-end) and the 5G testbed (MEC, 5G EVE Infrastructure) in Turin.

• **TC2.2.2:** CPO Backend - Charging station communication to test the communications between the CPO back-end and the Charging Stations in the 5G environment in terms of retrieval of metering data and actuation of control signals.

• **TC2.2.3:** Distributed Smart Charging in 5G Environment to test the decentralized control algorithm enabled by the iterative interactions among the Master Control Agent hosted by the MEC and many Local Control Agents via 5G.

• **TC2.2.4:** Distributed Smart Charging in 5G and CSP Layer Environment to test the decentralized control algorithm integrated with the CSP back-end (hosted by the MEC) in the 5G Environment, so as to validate the whole CSP Layer Environment.

• **TC2.2.5:** Distributed Smart Charging in 5G and Vertical Environment to test the integration between the CSP Layer Environment and the CPO back-end in absence of connected EVs, so as to validate the full ICT chain enabled by 5G.

• **TC2.2.6:** On Field End to End Smart Charging to test the E2E use case, providing the smart charging services via 5G with Electric Vehicles connected to the Charging Stations on field.

The performances of test cases are measured through the KPIs defined in D1.1B, which are reported in the KPI Visualization System by proper integration with the CSP Layer Environment.

Looking at the above plan, the reader can realize that, due to its incremental approach, the successful execution of some tests implies the validation of others. For example, the validation of TC2.2.4 implies the validation of TC2.2.3, the latter being defined to test a subset of the components and interfaces tested in TC2.2.4; this allows the verification of stability of the proposed solution over different Cycles. At the same time this approach allows to omit the execution of a test, in case components and interfaces needed to execute the higher-level test are made available; this is the case of TC2.2.5, which is implicitly executed in Cycle 2 in through the execution of TC2.2.6.

In Cycle 1 a set of pre-trial tests have been performed, to check the 5G connectivity in the demo site and validate the stand-alone operation of the controller in a lab environment without 5G connectivity. The test case TC2.2.3 has been successfully executed with 5G, validating the decentralized smart charging algorithm in the 5G EVE environment, working with simulated EV charging sessions. Test cases TC2.2.1 and TC2.2.2 have been designed and partially implemented in Cycle 1.

Cycle 2 has been dedicated to the execution of TC 2.2.4 (and then implicitly TC2.2.3) and, under some restrictions reported in the following, the E2E TC2.2.6 (and then implicitly TC2.2.5). The following sections describe the activities related to the design, implementation, integration, setup and execution of these test cases. Specifically, in Section 3.2.1, the status of the use case technical design, implementation and integration activities of Cycle 1 are presented.

In particular, different deployment architectures, as represented in Figure 20 B and C, has been produced both to include new (and more advanced) test cases, that make use of some additional components of the high-level
architecture (Figure 1 A) with respect to Cycle 1 activities, and to make use of a more flexible communication protocol among the Master Control Agent and the Local Control Agent.

During Cycle 2 pre-trial and integration activities has been planned and some on-field tests for TC 2.2.6 will be executed involving hardware components (both network and vertical, also including actual electrical equipment and loads). Indeed, the integration among Charge Advisor and CPO layer, as described in the following sections, will be tested using real charging stations, real electric vehicles and a 5G modem. Other from this hardware integration, Test Case 2.2.3 components (already tested in Cycle 1 trials) have been interconnected with Charge Advisor platform, so to provide a complete CPS layer implementation during Cycle 2. Moreover, the full chain for Use Case 2.2 has been tested by using IREN charging stations and electric vehicles, while in Cycle 3 the Enel X Way charging infrastructure will be integrated as well in the Use Case 2.2 chain.

For the MPC control strategy, we refer to the mathematical definitions and related decentralized algorithmic solution reported in D5.2A (Section 3.2.1.1 and 3.2.1.2, respectively).

### 3.2.1.1 Detailed control architecture

This section details the updates made on the Control Service Provider (CSP) layer during Cycle 2 activities. The old CSP layer architecture is presented in Figure 21, while the updated CSP layer architecture is presented in Figure 22. All the main software agents are basically kept unchanged (i.e., CSP Back-End - Charge Advisor, Master Control Agent, Local Control Agent, KPI Visualization System) except for the Local Control Agent Proxies, that are replaced by the MQTT Broker. Indeed, the interface between Master Control Agent and Local Control Agents has now been replaced from HTTP/REST interfaces to MQTT interface.

MQTT is a state-of-the-art Publisher/Subscriber protocol widely used in the context of IoT applications to ensure a set of (even low power) IoT devices to communicate each other or with a central/distributed control unit.
The choice to use MQTT instead of HTTP/REST made the communication among the software agents (Master Control Agent - Local Control Agents) more flexible than before, since the MQTT Broker takes care of automatic reconnection to the agents, message storing and disconnection notification. Moreover, multiple Local Control Agent inside the same UE are now possible without the Local Control Agent Proxy component, since the connections to the MQTT Broker are originated by the Local Control Agent themselves, and the communication happen on always-open TCP sockets handled by the MQTT Broker. This also reduced the network latency caused by multiple TCP hand-shakings: indeed, using HTTP/REST interfaces not all the HTTP servers implement the Keep-Alive functionality and, if available, the connection Keep-Alive service usually keeps the active TCP sockets on for a limited amount of time, while MQTT uses Keep-Alive by default and with heartbeat messages (with configurable frequency, 1 minute by default) to check the health status on the other end.
Moreover, MQTT offers the possibility to tag messages with a QoS value (0, 1 or 2), that incrementally guarantees that the message is actually delivered (0: no guarantees, 1: the message is guaranteed to be delivered at least one time to the recipients, 2: the message is guaranteed to be delivered exactly one time to the recipients).

Finally, MQTT offers same authentication and encryption functionalities as HTTP/REST, by exploiting login credentials and SSL/TLS over TCP traffic.

### 3.2.1.2 Control Service Provider implementation

Figure 21 shows how the Control Service Provider (CSP) back-end system is part of the architecture of UC2.2. The CSP Back-end was not part of the deployment architecture trialed in Cycle 1, but it has been fully integrated in the architecture for Cycle 2. The main task of the CSP Back-end is to orchestrate and intermediate the execution of the smart charging sessions between the Master Control Agent VNF and the charging stations operated by the Charging Point Operator (i.e., the e-Mobility platform).

The main service offered by the CSP back-end is Charge Advisor. The name recalls the Charge Advisor Platform developed from 2015 and owned by Ares2t (the Use Case Developer in LL2). Basically, Charge Advisor is an integrated platform providing the Electric Vehicle’s driver with trip planning and smart charging functionalities guaranteeing a more comfortable driver experience and enabling the provisioning of active demand services to relevant players of the electricity distribution system. The platform offers different services. In the Table 9 below, we report a selection of the Charge Advisor’s interfaces which the design and implementation of the CSP Back-end in 5G-Solutions started from.

<table>
<thead>
<tr>
<th>URI</th>
<th>Method</th>
<th>Called by</th>
</tr>
</thead>
<tbody>
<tr>
<td>api/em/LA_Update</td>
<td>POST</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>api/em/LM_Target</td>
<td>POST</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>api/em/LM_Charging_Request_Notification</td>
<td>POST</td>
<td>Charging Point Operator</td>
</tr>
<tr>
<td>api/em/LM_Charging_Session_Scheduling</td>
<td>POST</td>
<td>Charging Point Operator</td>
</tr>
<tr>
<td>api/em/LA_Meter_Readings</td>
<td>POST</td>
<td>Charging Point Operator</td>
</tr>
</tbody>
</table>

Here is a detailed description of the interfaces introduced in the above table:

1. **LA_Update**: interface used by the Distribution System Operator (DSO) to update the Point of Delivery (POD) which belongs to a specific Load Area.
2. **LA_Target**: interface used by the DSO to update the Load Area curves as the Power Threshold Curve and the Target Load Curve.
3. **Charging_Request_Notification**: interface used by the Charging Point Operator (CPO) to create a new electric vehicle charging request.
4. **Charging_Session_Scheduling**: interface used by the CPO to start scheduling all the EV charging requests defined in a Load Area. This request gathers all the necessary information about the Load Area curves, and all the charging request information and sends them to the Master Control Agent VNF which ultimately sends as response the optimal charging power for a specific Load Area.
5. **LA_Meter_Readings**: interface used by the CPO to send the actual charging power applied to the Load Area.

The modules of the Charge Advisor Platform being of interest for UC2.2 (the smart charging ones) have been re-designed and the CSP Backend Application Charge Advisor has been developed in Laravel 8, an open-source PHP web application framework. The overall business logic of the CSP Backend Application has been remodeled with respect to the original one as well as the set of interfaces (both server and end user side) which have been re-
designed and implemented ad-hoc to support the complete E2E development of UC2.2. From the deployment’s point of view, the CSP Backend Application has been containerized through the Docker platform (v. 20.10.5). This new technology will guarantee a faster, reliable, and more consistent deployment on any environment.

In Cycle 2, Charge Advisor has taken part to the execution of the TC 2.2.4 and TC 2.2.6. In particular, the TC 2.2.4 tested the integration between Charge Advisor and the Master Control Agent, where the former simulated various charging sessions with more than one vehicle to recharge and interrogated the Master Control Agent periodically (1 minute) to obtain the optimal charging power for each active charging session (See results at D5.3B, paragraph 4.2.1).

TC 2.2.6 is the evolution of TC 2.2.4 and tests the end-to-end communication of the UC 2.2 and a real charging session has been executed with success. In this Test Case, a 5 minutes sampling time has been chosen. Charge Advisor receives periodic requests from the CPO back-end installed in the 5G-EVE RAN on two particular endpoints (see descriptions above) through the HTTP/REST protocol:

1. **LA_Meter_Readings**
2. **Charging_Session_Scheduling**.

“LA_Meter_Readings” interface allows to receive the most updated data regarding the charging sessions for each vehicle. This is necessary to Charge Advisor to estimate the recharging status of the vehicle for the next recharging scheduling.

“Charging_Session_Scheduling” interface allows to receive the optimal charging power for each active session defined in a particular Load Area. In this request, Charge Advisor pre-processes and prepares the inputs for each active sessions according to the most updated recharging data received through “LA_Meter_Readings” interface. At this stage of the scheduling request, Charge Advisor must estimate the recharging status of each vehicle for the next actuation time. Furthermore, Charge advisor stores in its own database the Target and Power Threshold curves which define respectively the target and limit aggregate power consumption for all the active electric vehicles associated to the same Load Area in a certain amount of time (maximum duration of the charging sessions). Charge Advisor is responsible to gather and pre-processes all these information and send them in a request to the Master Control Agent which will be responsible to return the optimal recharging power.

Figure 23 shows the timing of the Charge Advisor interfaces called by the E-Mobility Platform. Charge Advisor VNF and Master Control Agent VNF are located in the 5G-EVE MEC, whilst the E-Mobility Platform or CPO Back-end is placed in the 5G-EVE RAN.

![Figure 23](image.png)

**Figure 23** CSP Back-end: periodical communication with E-Mobility Platform and Master Control Agent VNF for TC2.2.6
3.2.1.3 **Detailed sequence diagrams**

Given the update of the Use Case architecture described above, an updated Message Sequence Chart has been reported in the following Figure 24, Figure 25, and Figure 26.

![Message Sequence Chart](image)

**Figure 24 Use Case 2.2 - Discovery of Local Control Agents**

The first Message Sequence Chart (Figure 12) represents the discovery process, that now is radically changed since the introduction of MQTT protocol instead of HTTP/REST. In this current implementation, a Local Control Agent spawns with an associated ID that should be communicated to the Master Control Agent. This ID is the same ID of its associated Electric Vehicle Supply Equipment (EVSE). In order to communicate that it is alive and its EVSE_ID, it sends a message on the master/agent topic, so that the MQTT Broker notifies all the agents that have subscribed to that topic (in this case the Master Control Agent only). The Master Control Agent, then, replies to the specific Local Control Agent some control parameters (to be used in the optimization problem calculation later on) by using the parameters/{EVSE_ID} topic (where {EVSE_ID} is substituted with the EVSE_ID of the specific Local Control Agent in this topic and in all the following ones). In this way the Master Control Agent is aware that there is a Local Control Agent responsible computing charging schedules for charging session happening on EVSE with ID {EVSE_ID}. 
Figure 25 Use Case 2.2 - Decentralized optimization problem iteration

Then, when a Scheduling request arrives from the E-Mobility Platform (e.g., in a periodic way), the request is forwarded to Charge Advisor, that forwards it to the Master Control Agent using an HTTP/REST interface. From this point on, the decentralized computation of the optimal schedule is basically as presented in D5.2A: once the Master Control Agent receives the Scheduling request, it analyses it to understand the involved EVSEs, and so the involved Local Control Agents associated to these EVSEs; then, it starts the involved Local Control Agents sending all the relevant data to the involved Local Control Agent by using the start_computation/{EVSE_ID} topic. Once the Local Control Agent receives this message from the MQTT Broker, it starts computing its optimization problem, and once finished it sends back to the Master Control Agent the partial solution by using the intermediate_results/{EVSE_ID} topic. Once the Master Control Agent collects the partial results from all the active Local Control Agents, then it computes its optimization problem and computes the residuals between the partial solutions computed by the Local Control Agents and its partial solution. If the desired tolerance is not reached (i.e., if the residuals are greater than a certain threshold), then the Master Control Agent asks the Local Control Agents to update their Lagrangian Multipliers by sending its partial solution to the update_multipliers/{EVSEID} topic. Once a Local Control Agent receives the message through this topic, it updates its Lagrangian Multipliers and sends to the Master Control Agent the updated Lagrangian Multipliers by using the lagrangian_multipliers/{EVSE_ID} topic. Once the Master Control Agent receives the Lagrangian Multipliers from all the involved Local Control Agent it starts back with a message sent to the start_computation/{EVSE_ID} topic.
In case, instead, the tolerance is reached, then the Master Control Agent packs the computed optimal scheduling to be sent back to Charge Advisor as reply to the previous HTTP/REST call. At the end Charge Advisor takes care to send the Scheduling back to the E-Mobility Platform back end to be actuated on the involved charging stations (EVSEs).

3.2.1.4 **Vertical Service development and integration**

The reference integration framework for the Vertical Service has been the one developed in the ICT17 project 5G EVE. In this respect, we recall here that in the reference integration framework, vertical industries (defined as “Verticals” from now on) can test and evaluate the performance of their Vertical Services in a realistic 5G environment. This approach allows the Verticals to verify the compliance of the relevant network related KPIs with the expected service performance. Once the Vertical Service development is completed, the integration phase takes place and starts with the onboarding of the necessary VNFs. Indeed, as the design of the Vertical Service is completed, the procedure of the instantiation of all VNFs in 5G EVE facility gets started. A set of procedures takes place as follows:

1. Definition of the network interfaces in the VM, installation of python2 (necessary package to allow the Runtime Configurator to work during the 5G experiment execution), and snapshot of the VM.
2. The VNF package (this tar.gz file describes the Network Service and points the image of the VM) is uploaded by the Site Manager in the VNF repository of the facility (the Italian Site, in our case).
3. Design and upload of the Blueprints/Descriptors to configure the Vertical Service in the 5G EVE facility via web portal as we will explain in the following.

Regarding the last point, the following blueprints and descriptors need to be prepared: VSB, VSB NSD, CTX, CTX NSD, TCB, and EXP NSD.

In particular, the Context Blueprint (CTX) and Context Descriptors (CTX NSD) are the only ones which are not edited from scratch by the Use Case Developer. These are standard templates which define an operational context for the network service and that the Use Case Developer can suitably configure according to the scope...
of each single experiment execution. They are used to define experimental conditions for the service described in the VSB, as artificial background traffic, artificial delay and similar.

The Vertical Service Blueprint (VSB) describes in a more formal and structured way the service that the use case Responsible (Iren) wants to validate and to test on the 5G EVE platform. The VSB is written by the Use Case Developer who interacts with the use case Responsible to gather information about the service and the kind of experiments they want to run on it. The VSB can be represented in JSON or YAML format, and a set of features must be determined in this file. In particular, four components must be configured, namely, VNF, VL, CP, and SAP. In particular, the TC2.2.4 and TC2.2.6 are configured with:

1. Atomic functional components (VNF)
   a. Master_control_agent (mca)
   b. MQTT Broker (mqtt)
   c. Charge Advisor (ca)

2. Virtual Link (VL):
   a. vl_master_control_agent_ext_in
   b. vl_master_control_agent_data
   c. vl_master_control_agent_eve
   d. vl_master_control_agent_mgmt

3. Connection Point (CP)
   cp_master_control_agent_eve,
   cp_master_control_agent_data,
   cp_master_control_agent_mgmt,
   cp_ca_mgmt
   cp_ca_data
   cp_ca_ext_in
   cp_mqtt_data
   cp_mqtt_mgmt
   cp_mqtt_eve

4. Service Access Point (SAP)
   sap_master_control_agent_eve,
   sap_master_control_agent_mgmt

Figure 27 below clearly shows the structure of the Vertical Service Blueprint for UC2.2 in reference to TC2.2.4 and TC2.2.6 from the 5G EVE portal.
In UC2.2, the CTX and the CTX NSD of the “Delay Generator” have been chosen and the related JSON files have been configured with suitable parameters. In Cycle 1, these parameters have no relevance, since the Test Cases selected for Cycle 1, namely the TC2.2.3, reflect a basic implementation of UC2.2 and they are meant to be integrated and more extensively trialed in Cycle 2 in preparation of the final integration to be trialed in Cycle 3. The CTX describes a template for network elements to define an operational context for the network service. The CBs are used to define experimental conditions for the service described in the VSB such as artificial background traffic, artificial delay and so on. Similar to the VSB, the CB can include some parameters to customize its components. Figure 28 below shows that the CB components, which are as follows:

1. Atomical functional components (VNF)
   a. Delay_generator
2. Virtual Link (VL)
   a. vl_dg_out
   b. vl_dg_in
   c. vl_dg_mgmt
3. Connection Point (CP)
   a. cp_dg_ext_out,
   b. cp_dg_in,
   c. cp_dg_mgmt,
4. Service Access Point (SAP)
   a. sap_dg_in,
   b. sap_dg_out,
   c. sap_dg_mgmt
For UC2.2, the Test Case Blueprint is set in such a way that both Master and Local Control Agents are able to get the experiment ID from the 5G EVE facility. This ID is successively sent to 5G-Solutions Visualization System in order to create/start an identifiable experiment. For this reason, an instruction to execute a shell script has been included in the file configuration.

Once all the configuration files are ready, the next step involves the upload of the blueprints and descriptors and the deployment of the VNF in the “Design Experiment” section of the 5G EVE Portal. In Cycle 2, the configuration procedure for TC2.2.4 and 2.2.6 has been implemented as done with TC2.2.3 in Cycle 1. For further details, we refer to D5.2A (Section 3.2.1).

For the TC2.2.4 and 2.2.6, there are two types of KPIs, namely, Vertical Service KPIs and Network KPIs. These can be summarized in the following table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregated charging power reference curve deviation</td>
<td>Vertical Service</td>
<td>kW</td>
</tr>
<tr>
<td>State of charge</td>
<td>Vertical Service</td>
<td>kWh</td>
</tr>
<tr>
<td>Sampling time</td>
<td>Vertical Service</td>
<td>s</td>
</tr>
<tr>
<td>Latency Userplane RTT</td>
<td>Network</td>
<td>ms</td>
</tr>
<tr>
<td>Availability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>Reliability</td>
<td>Network</td>
<td>%</td>
</tr>
</tbody>
</table>

Here is below a description for each of the KPIs. Note that only the first one is generated by the VNF of the Master Control Agent. The others are generated by the 5G EVE facility during the experiment activation.
1. **Aggregated charging power reference curve deviation**: Deviation between the target and the aggregated charging power curve.
2. **State of charge**: State-of-charge evolution experienced by each vehicle.
3. **Sampling time**: Sampling time assigned to the smart-charging system.
4. **Latency UserPlane RTT**: Round Trip Time experienced by the VNF deployed between sending the request to the 5G EVE facility component and receiving a response.
5. **Availability**: Amount of uptime in a network system over a specific time interval. Uptime refers to the amount of time a network is fully operational.
6. **Reliability**: Percentage of assurance that the delivery of data to intended recipients was successful.

Finally, Table 11 shows the list of APIs to the 5G-Solutions KPI Visualization System (KPI-VS). In particular the “**Start Notification**” interface is responsible to create a unique session for each test case execution activated on the 5G-Solutions KPI-VS side. This is the first request sent to KPI-VS by the VNF Master Control Agent. Consequently, the same VNF starts sending the Vertical Service KPIs through “**Vertical Service KPI sending**” API. All these values are collected by the KPI-VS which make them visualizable in real time. At the end of the test case execution, a “**Stop Notification**” is sent to KPI-VS. The Start/Stop Notifications are not only responsible to create/terminate the test case execution, but they are in charge of providing the (unique) test case execution identifier related to one experiment ID to the KPI-VS which then retrieves and filters all Network KPIs from the 5G EVE facility on the basis of the experiment ID. The reference implementation of the above-mentioned interfaces can be found in [10].

### Table 11 API list to the KPI-VS for TC2.2.4 and TC2.2.6 in Cycle 2

<table>
<thead>
<tr>
<th>Name Interface</th>
<th>Method</th>
<th>URI</th>
<th>KPIs associated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Notification</td>
<td>POST</td>
<td><a href="https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati">https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati</a> on</td>
<td>All Network KPIs (Latency Userplane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
<tr>
<td>Stop Notification</td>
<td>POST</td>
<td><a href="https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati">https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati</a> on</td>
<td>All Network KPIs (Latency Userplane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
<tr>
<td>Vertical Service KPI sending</td>
<td>POST</td>
<td><a href="https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati">https://ingress.kpis-5gsolutions.eu/5gsolutions/data-collector/notificati</a> on</td>
<td>Vertical Service KPI (Aggregated charging power reference curve deviation, State of charge, Sampling time)</td>
</tr>
</tbody>
</table>

### 3.2.2 Overview of the Test Setup According to the Plan Described in D2.4B

In this section, the advancements for setup activities concerning the energy and the 5G experimental facility are detailed for Cycle 2. Though the energy facility has been designed and was planned to be fully operative in Q4/2021, a series of delays in the innovative EV charger, namely the JuiceBox 25kW with the integrated 5G modem occurred during Cycle 2 and required a re-planning of the trial activities in Cycle 2. The 5G facility has been extended before Cycle 1 specifically to support the use case development but it was not available to support test case execution in Cycle 2.
3.2.2.1 **Energy facility setup**

The JuiceBox 25kW DC, Enel X Way’s proprietary EV charger with 5G connectivity, was under development in Cycle 1 and the first units should have been available for testing in Q4/2021 after the deployment and integration in the testing facility provided by the UC Owner (Iren) the City of Turin (Italy). A series of delays in the provisioning require for a different energy facility setup in Cycle 2. In Cycle 2 the Vertical Partner (Enel X Way) has enacted the necessary actions to provide three Juice2Grid V2G (15 kW) to install and enhance with 5G connectivity in Enel’s facilities in the City of Turin, Corso Appio Claudio (see Figure 54) by July 2022.

The energy facility made available by UC Owner (Iren) consists of the company parking of the headquarter of Iren Energia (the Energy Division of the company). It is in the City of Turin, Corso Svizzera 95 (see Figure 29). The parking is a three-story parking that hosts the company fleet. A photovoltaic system of approximately 50kW is installed on the rooftop of the parking.

![Figure 29 UC2.2 test site for trial activities](image)

The parking is equipped with 11 EV chargers, 9 of them are AC chargers (Alfen type 22 or 11 kW) and 2 are 10 kW DC prototypal bi-directional DC chargers (see Figure 30.a). The EV chargers used in Cycle 2 have been connected to Huawei CPE Pro 5G Modem (see Figure 14 and Figure 30.b)

![Figure 30 Energy facility set up for TC2.2.6](image)
The executions of test case TC2.2.6 has been performed using two EVs in the Iren fleet: two Renault Zoe as shown in Figure 31.

![Figure 31 The EVs in Test Case TC2.2.6](image)

### 3.2.2.2 5G facility setup

As reported in D5.2A, the testing facility provided by Iren to host UC2.2 was not originally covered by the ICT-17 5G facility, namely, 5G EVE. For this reason, an explicit request has been submitted to the Site Manager (TIM) of the Italian Site of the 5G EVE facility as soon as the energy facility was identified by the use case owner (Iren) in Q3/2019, before the LL2 official starting date. The use case owner received in Q2/2020 a first technical confirmation of the commitment from the Site Manager to extend the above-mentioned facility to cover the energy facility hosting UC2.2. In Cycle 1, the extension of the 5G EVE facility has been tested by executing TC 2.2.3 with 5G in the specific area (see Figure 29). Another extension planned in Cycle 3 concerns the connectivity between the Vertical Service deployed in the 5G facility and the E-Mobility Platform by the UC Owner (Enel X Way). The definition and setup of the connectivity is ongoing and required effort to the UC Owner from one side and the Site Manager (TIM) from the other one.

Due to an issue occurring in the Spanish Site of the platform, the 5G EVE web portal was not reached and all UCs in LL2 relied on the physical infrastructure of the Italian Site of the 5G EVE Platform (i.e., the Radio Access Network, where available in the City of Turin) only. As a consequence, the 5G EVE web portal was not reached and during the execution of test cases TC2.1.1 and TC2.1.3 there was no mean:

1) to dynamically deploy the necessary VNF chain 
2) to schedule any test case execution
3) to integrate the 5G-Solutions CDSO via 5G EVE north-bound APIs
4) to communicate Network KPIs to the KPI Visualization System

For this reason, in the execution of test cases reported in the following,

1) the VNF chain has been deployed manually,
2) there was no schedule through the 5G EVE web portal,
3) there was no trial with CDSO
4) it was not possible to collect the Network KPIs by the KPI Visualization System.
In May 2022 the 5G coverage in the area selected for UC 2.2 (see Figure 29) was no more available, therefore the test cases TC2.2.4 and 2.2.6 have been executed with 5G equipment (5G modem + 5G EVE SIM card) connected to a 4G+ node instead of a 5G one, since the physical infrastructure of the 5G EVE facility was not supporting.

### 3.2.3 Execution of Test Case TC2.2.4

Test Case 2.2.4 is built on top of Test Case 2.2.3. This means that all the components of TC 2.2.3 (see D5.2A section 3.2.3), except for Local Control Agent Proxy, that is now replaced by MQTT Broker, appears also in TC 2.2.4. Moreover, TC 2.2.4 includes also Charge Advisor component, that orchestrates the communication and timing between the E-Mobility Platform back end and the Master Control Agent.

The CSP back end, as in TC 2.2.3, is completely developed as Docker Containers, to facilitate the deployment as VNFs in the facility. In particular, the Master Control Agent and MQTT Broker are deployed as separate VNF at MEC level. This is to maintain scalability of the proposed approach, since the MQTT Broker is a central node for all the communications between Master Control Agent and Local Control Agents, so multiple MQTT Brokers can be spawned to maintain load balancing. In Test Case 2.2.4 only one MQTT Broker is envisaged since the small number of Local Control Agents involved.

Both Master Control Agent and Local Control Agents are still developed in Python3 and make use of the Eclipse Paho MQTT Client Python library (other the other libraries described in D5.2A section 3.2.3) to connect to the MQTT Broker. The MQTT Broker used is Eclipse Mosquitto, an open-source and very supported MQTT Broker, that is also directly available from the Docker Hub to download as Docker Container.

Charge Advisor is based on the Laravel framework version 8 and is written in PHP, and it is completely deployed through a set of docker containers. The communication between the CPO Backend (i.e., E-mobility Platform) and the Charge Advisor relies on three different endpoints (LA_Meter_Readings, Charging_Session_Scheduling and LM_Charging_Request_Notification) shared by the latter using the HTTP/REST Protocol.

The specification of Scheduling request and Scheduling response messages between Charge Advisor and Master Control Agent has been developed ad-hoc for this Test Case and relies on HTTP/REST.

The deployment of all the containers is still managed by Docker Compose by running a set of scripts asking for configuration parameters (e.g., the MQTT Broker IP address, the number of Local Control Agents to be spawned in a single physical machine in the RAN, etc.).

For Test Case 2.2.4, the Samsung 5G smartphone has been replaced with a Huawei CPE 5G modem, that is provided with Wi-Fi Access Point and Ethernet ports, so to have a stabler, more configurable and more performant 5G connectivity. This also simplifies the execution of TC 2.2.4 and the analysis of the results, since the connection between the 5G modem and the laptop hosting the Local Control Agent is now ensured by Ethernet connection, that is way more reliable and stable than Wi-Fi hotspot or USB tethering, so we can ensure that the network KPIs are not influenced by poor connections at field side.
3.2.3.1 **Purpose of the Test**

The purpose of Test Case 2.2.4 is to validate the full CSP Layer chain, and so including the algorithmic / decentralized computation task (Master Control Agent - Local Control Agents, as tested in Test Case 2.2.3) and the communication / coordination task from Charge Advisor. Moreover, the HTTP/REST interface between Charge Advisor and Master Control Agent is to be validated, in order to understand if it should be updated / upgraded in the next cycle activities.

3.2.3.2 **Test Setup**

All the tests for Test Case 2.2.4 will be performed in Iren’s premises in Turin in a lab environment. This is because in Test Case 2.2.4 no electrical load is still involved (but it will be as Test Case 2.2.4 and Test Case 2.2.5 will be merged in Test Case 2.2.6, planned for Cycle 3). Test Case 2.2.4 involves the following components:

- Huawei CPE 5G modem (see Figure 30.b)
- Laptop connected via ethernet cable to the 5G modem and running Local Control Agents (see Figure 33)
- CDSO integrated with the 5G EVE facility for dynamic experiment deployment and activation
- The full VNF chain deployed:
  - Delay Generator as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  - Master Control Agent as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  - MQTT Broker as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  - Charge Advisor as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
- 5G Solutions KPI-VS through the suitable interfaces defined in the use case implementation and integration activities.

As the 5G modem is connected to the 5G EVE APN and the two Local Control Agents (one for each Electric Vehicle in the test case execution) are ready, the test is ready to be run. Once the CDSO starts the execution, all the VNFs are instantiated in 5G EVE MEC and the execution of the test begins.
3.2.3.3 **Challenges**

The main challenges for Test Case 2.2.4 are:

- Test the Charge Advisor - Master Control Agent interface
- Test the coordination and timing between Charge Advisor and Master Control Agent
- Test the possibility to set a timeout for the distributed optimization problem computation

3.2.3.4 **Planned Execution**

The execution of TC2.2.4 has been trialed with 5G in Cycle 2, in line with the planned execution (reported in D2.4B). The results obtained so (reported in D5.3B) provide inputs for updates / upgrades in the components for trials in Cycle 3.

A first set of tests aimed at validating the interface between Charge Advisor and Master Control Agent and the new MQTT protocol communication between Master Control Agent and Local Control Agents without setting up a timeout for the computation of the optimal scheduling. This gives the possibility to check the results and the correct exchange of relevant information between the software agents without particular time constraints.

A second set of tests, instead, introduces the optimal scheduling computation timeout and the evaluation of the effect of this timeout on the optimal solution found.

In both the test phases a sampling time for the control process is set to 1 minute, i.e., a scheduling request from Charge Advisor to the Master Control Agent:

- arrives up to each minute in the first set of tests
  - a new scheduling request is sent just after the previous scheduling response if this response arrives within 1 minute, or after exactly 1 minute otherwise
- arrives exactly each minute in the second set of tests, since a timeout ensures that the distributed computation lasts less than 1 minute

3.2.4 **Execution of Test Case TC2.2.6**

Test Case 2.2.6 represents the E2E communication between all the systems defined in the deployment architecture depicted in Figure 34. TC 2.2.6 incorporates TC 2.2.4 in the actual smart charging services to remotely control the Charging Stations on field in the load area The via 5G during the charging session involving actual Electric Vehicles.
In TC 2.2.6, the CSP back-end (Charge Advisor), the Master Control Agent and the MQTT Broker are completely developed as Docker Containers, and they are deployed as separate VNF at MEC level. The Local control agents are deployed in a physical machine in the RAN and finally the new element of the Test Case 2.2.6 with respect to the predecessor TC 2.2.4 is the presence of the Electric Vehicles and the E-Mobility Platform which stores the software solution that interacts with the Charging Stations through the OCPP Protocol.

![Figure 34 TC 2.2.6 deployment architecture](image)

### 3.2.4.1 Purpose of the Test

TC 2.2.6 is the most important test case for the UC 2.2, since it validates the E2E communication between all the systems involved in the reference architecture and shows how the benefits of the 5G can improve the performance of the smart charging functionalities in the industrially relevant Smart Energy scenario.

### 3.2.4.2 Test Setup

TC 2.2.6 is executed by following all the tasks defined in this checklist:

1) Arrival of the electric vehicles on site (Load Area, see Figure 35.a)
2) Get info regarding the Vehicle State of Charge (see Figure 35.b)
3) Start the periodic job regarding the communication between E-Mobility Platform and Charge Advisor (LM_Meter_readings and Charging_Session_Scheduling, see Section “Control Service Provider Implementation”). The sampling time is 5 minutes.
4) Definition of the Target and Power Threshold curve, which define the objective and power limit curve respectively. These curves are essentials for the definition of the optimization problem. These curves are simulated by Charge Advisor VNF which will then use it to formulate the input request for the Master Control Agent VNF.
5) Start of the charging session: EV Charging Station socket plugged to the electric vehicle and Notification Request automatically sent to Charge Advisor from E-Mobility Platform through a dedicated interface (LM_Charging_Request_Notification) using HTTP/REST Protocol.
6) Experiment Execution Monitoring: The periodical job started at 3) automatically executes the charging session for recharging all electric vehicles. The session is mainly monitored on four sides: on-field charging stations, OCPP Back-end, Charge Advisor GUI, Master Control Agent computation logs.
7) End of the charging session: EV Charging station socket unplugged from the Electric Vehicle and subsequent Stop Notification Request sent to Charge Advisor from the E-Mobility Platform. All the charging sessions become inactive, and the experiment is completed.

![Load Area](image1.png) ![Vehicle State of Charge](image2.png)

Figure 35 Test Case TC2.2.6 Load Area (a) and Vehicle State of Charge (b)

3.2.4.3 Challenges

The main challenges for Test Case 2.2.6 are:

- Test the suitable communication among the endpoints involved in the test case execution:
  - The EV charger via the E-Mobility Platform
  - The Local Control Agents
  - The Vertical Services
- Test communication and data exchange between:
  - E-Mobility Platform and the Vertical Service (reference VNF: Charge Advisor)
  - Local Control Agents and The Vertical Service (reference VNF: Master Control Agent)
- Test the charging session optimization and control via the VNF chain allowing distributing the computational effort.

3.2.4.4 Planned execution

As planned in D2.4B, the execution of the TC2.2.6 was expected in Cycle 2. On 24th and 25th May 2022, a set of tests have been executed for TC 2.2.6. This has been the first test that experimented the E2E communication between all the systems defined in the reference architecture. The communication between Charge Advisor and the Master Control Agent was already tested in TC 2.2.4, whilst the communication between Charge Advisor and the E-Mobility Platform was tested and performed with success at the first trial. However, the test was performed with 4G connectivity due to issues of the 5G coverage in the designed testing area.

3.2.5 Effect of the COVID

For this Use Case, no direct impact on the setup and implementation activities has been registered. As planned, we started from lab tests to execute the integration test related to TC2.2.4 and 2.2.6 in the 5G facility. COVID and the globally delayed supply chain has impacted has delayed the development of the prototype JuiceBox DC to a level that required Enel X Way to opt for the choice of the Juice2Grid V2G 15 kW for the UC 2.2.
3.2.6 Mitigation Measures

Differently from the initial plan, the actual execution of test cases TC2.2.4 and 2.2.6 showed that no 5G coverage was present in the test field (as explained in Section 3.2.2.2). This mitigation action requires:

- Performing the trials with 4G+
- Selecting a different test field with an energy facility with similar characteristics so to move the test case execution in Cycle 3 in an area with adequate 5G coverage
- Opting for the enhancement of the Jucie2Grid V2G 15 kW with 5G communication instead of using the innovative JuiceBox DC under development.

3.2.7 Next Steps

The most important step will be moving the trials in another site with 5G coverage. A suitable test field has been already identified and connectivity tests successfully executed. In June 2022 test cases TC2.2.4 and 2.2.6 are going to be executed in the new energy facility with 5G and all results will be reported in Cycle 3.

Moreover, due to the unavailability of the 5G EVE platform, test cases TC2.2.4 and 2.2.6 demonstrated the communication of Vertical KPIs from the Vertical Service to the KPI Visualization System but no network KPI has been retrieved by the KPI Visualization System from the 5G EVE platform. No test case execution was orchestrated by CDSO since the 5G EVE north-bound APIs were not available. These deviations will be accommodated in Cycle 3 if the 5G EVE platform will be completely recovered and will be back to full operation.

Finally, according to the results of the above-mentioned activities in Cycle 2, all partners will be involved in the definition of final integrated use case in different relevant scenarios for Cycle 3 being decisive for the collection and evaluation of the Network and Vertical KPIs.

3.3 UC2.3 Electricity Network Frequency Stability

This section reports the technical design, implementation, integration, setup and validation of UC2.3. This use case focuses on the development of a 5G Vertical Service enabling the participation of charging Electric Vehicles (EVs) to the provisioning of electricity network frequency regulation services. The service is offered by the Charging Point Operator (CPO) in a market managed by the Transmission System Operator (TSO), which is the only responsible for frequency stability. The TSO may accept the bid and may ask the CPO for activation of the service when needed, and only after verification that it is functional to enforce frequency stability.

Specifically, the 5G Vertical Service leverages 5G technology to enable (i) the gathering of frequency measurements from a meter hosted by a Master Charging Station, (ii) the computation of frequency-driven power deviations from nominal EV charging power setpoints, operated by software agents hosted in the MEC, and (iii) the spreading of power deviations to the involved Charging Stations for actuation.

As in practice the frequency measured in different nodes of the network is the same, the UC is motivated by the idea of using just one (or a very limited) number of frequency meters to drive the behavior of a large number of Charging Stations; on the contrary, providing each of them with a meter would impair the economic viability of the service. As the service requires that the measurement-computation-actuation chain is executed in a very short time period (a delay budget of 300 ms), and any deviations from the agreed service would imply economic penalties for the CPO delivering the service, the very low latency and high reliability offered by 5G communications are here considered enabling factors. The reader can refer to D1.1B for a detailed description of the UC.

The physical principles at the basis of the impact changes in the power demand have on the electricity network frequency, together with the rationale at the basis of EVs participation to the frequency regulation, have been presented in detail in D5.2A and are not reported here for the sake of document readability. The result of that analysis is that, from a vertical perspective, the addressed problem is reconducted to the one of generating power-frequency curves, which depend on the nominal charging power and then are personalized for each charging EV, which are used to compute the power deviations in response to frequency deviations from the...
nominal value. The composition of the power-frequency curves related to the involved EVs generate an aggregated power-frequency curve which represents the service offered by the CPO to the TSO. A first possible approach for frequency regulation has been developed in Cycle 1 and reported in D5.2 A. For sake of clarity of the presentation, it is also reported in Section 3.3.1.2 of this deliverable; this approach is the one actually implemented in the project to provide a proof-of-concept the value 5G connectivity brings to the Use Case. In addition, an extended approach has been developed in Cycle 2 (here reported as Second Approach in section 3.3.1.3, which takes into account a number of additional requirements connected to drivers’ preferences (like as in Use Case 2.2).

Figure 36 UC 2.3 - Reference architecture

All UC testing activities leverage the 5G EVE infrastructure and the Energy facility identified in Turin. As for UC 2.2, the development of the E2E use case requires interventions at different levels, including the implementation of a controller (Local Control Agent) hosting the power-frequency curve, the update of the vertical energy infrastructure, the setup of the 5G facility, and the integration among them. Keeping in mind the target E2E use case and the reference architecture (see Figure 36), also for UC2.3 an incremental validation plan has been established in D2.4B. The test cases are here briefly summarized in terms of key objectives.

- **TC2.3.1: High-Sampling-Rate Frequency and Power Signals Communications**
  To test the communication of simulated high sampling rate frequency measurements to the Local Control Agents and, in response, the spread of updated power deviations. Source node (frequency meter
/ IoT Agent in the Master Charging Station) and destination nodes (IoT Agents / actuators of the involved Charging Stations) are emulated.

- **TC2.3.2: Frequency Measurements and Communications to MEC**
  As in TC2.3.1, but the source node is a real frequency meter taking measurements from the real electricity network.

- **TC2.3.3: Power Signal Communications and Actuations**
  As in TC2.3.1, but the destination node is a real charging station.

- **TC2.3.4: On Field End to End Frequency Regulation**
  This is a test of the E2E use case, in which the source node is a real frequency meter taking measurements from the real electricity network and the destination nodes host one or more real charging stations where EV charging sessions are ongoing.

The performances of test cases are measured through the KPIs defined in D1.1B, which are reported in the KPI Visualization System by proper integration with the CSP Layer Environment.

Again, due to its incremental approach, the successful execution of some tests implies the validation of others. This allows the verification of stability of the proposed solution over different Cycles and the possibility of omitting the execution of a test in case components and interfaces needed to execute the higher-level test are made available.

Cycle 1 has been mainly focused on the design of test cases. A set of pre-trial tests have been performed to check the 5G connectivity in the demo site and validate the stand-alone operation of the control loop in a lab environment without 5G connectivity.

Cycle 2 has been dedicated to the execution of **TC2.3.1** and **TC2.3.2**. The following sections describe the activities related to the design, implementation, integration, setup and execution of these test cases. Specifically, in Section 3.3.1, the status of the use case technical design, implementation and integration at the end of Cycle 2 is reported, the implementation of the main components of the architecture, and the deployment framework to integrate TC2.3.1 and TC2.3.2 in the 5G facility. The main setup activities concerning the energy facility and the 5G facility are reported in Section 3.3.2.1 and 3.3.2.2, respectively. Finally, in Sections 3.3.3 and 3.3.4, the execution of TC2.3.1 and TC2.3.2 is presented as well as the addressed challenges, risk and mitigation actions, and the next steps for the complete deployment of the Vertical Service. This last section anticipates some considerations gained through the analysis of the achieved results reported in D5.3B.

### 3.3.1 Use Case Technical Design and Implementation

In this section, with reference to the UC 2.3 architecture in Figure 36, some approaches for the design of Use Case 2.3 algorithms for the computation of Power-Frequency curves for each Charging Session for frequency regulation are presented and analyzed, as detailed in the following subsections.

Moreover, a specific interface for IoT Agent - Local Control Agent communication has been developed in Cycle 2 in order to enable Charging Stations to send frequency measurements from an integrated frequency meter (installed inside a Master Charging Station) and to receive updated power setpoints computed by the Local Control Agents in response to a frequency disturbance event.

In addition, during Cycle 2 activities, an actual frequency meter taking measurements from the electricity network has been put in place and integrated (by the means of the over-mentioned interface and a 5G modem) with the Control Service Provider (CSP) layer, in order to validate the Use Case with real frequency measurements (and simulated charging stations/electric vehicles, which will be replaced and tested by their real counterparts in Cycle 3).
3.3.1.1 The role of EV charging in Frequency Regulation

The main idea of UC2.3 is then to contribute to the network frequency regulation acting on the flexible load. The functioning of the flexible load is reversed with respect to the frequency control loop of the generators:

- **Sub-synchronous**: if the network frequency goes down it means that there is less produced power than the consumed one. Our controllers will change the power setpoints of the controllable part of \( P(t) \), so that the EVs will continue the charging process with less power (or they can even provide power to the grid, if vehicle-to-grid (V2G) is available);
- **Over-synchronous**: if the network frequency goes up, it means that there is more power production than the consumed one. In this case, our controllers will change the power setpoints of the controllable part of \( P(t) \), so that the EVs will continue the charging process with more power (or they can even reduce the power injection to grid, if vehicle-to-grid (V2G) is available).

In what follows, we will give examples to clearly understand the concept behind UC2.3. For simplicity, the following considers only the case where the controller implemented on the charging station is a simple Proportional (P) controller with gain \( K_p \). There are three main cases to be considered in order to tune the controller gain \( K_p \):

1. EVs that are not charging but are connected to charging stations and are available for frequency regulation.
2. EVs are charging in an uncontrolled way (i.e., at maximum power).
3. EVs are charging according to what specified in UC2.2 (smart charging).

3.3.1.2 First approach

In this subsection the first approach developed in Cycle 1 and described in D5.2 A, has been reported here for the sake of readability of the overall section.

In this first approach, three possible cases are presented for generation of power-frequency curves for PEVs respectively representing a) standby case, b) uncontrolled charging case c) smart charging case.

For the first case, the EV is not charging, but it is connected to a charging station, and it is at disposal for frequency control. In this case, the behavior will be like in Figure 37. The \( K_p \) parameter of the Proportional (P) controller can be set as \( K_p = \frac{P_{\text{max}}}{\Delta\omega_{\text{max}}} \), where \( P_{\text{max}} \) is the maximum power which the EV can absorb/release while \( \Delta\omega_{\text{max}} \) is the maximum admissible frequency deviation from the nominal frequency. The normal operational practice within the European power systems is to keep frequency deviations less than +/-1% of the nominal value ENTSO-E [13]. In this way, in case of a frequency error of \( \Delta\omega_{\text{max}} \), the EV can contribute with the maximum power. It is possible to notice that in this case there is no needs to reach a certain desired final SoC since the owner of the EV wants just to provide a service to the network.
In the second case, the EV is charging at maximum power (uncontrolled charging), so we lose part of the control flexibility as there is no way to consume more energy, as shown in Figure 38. In this case, the $K_p$ parameter of the P controller can be set as:

$$K_p = \begin{cases} \frac{P_{\text{max}}}{\Delta \omega_{\text{max}}} & \text{if } \Delta \omega < 0 \\ 0 & \text{if } \Delta \omega \geq 0 \end{cases}$$

In this case, since no desired SoC is specified, nor a departure time is specified, there is no need to modulate $K_p$ based on user preferences. Also in this case, if $\Delta \omega_{\text{max}}$ is measured from the network, then the vehicle will charge at no power (or even it can release up to $P_{\text{max}}^{\text{release}}$ to the network if V2G is available, with $P_{\text{max}} = P_{\text{max}}^{\text{charge}} + P_{\text{max}}^{\text{release}}$, while, if V2G is not available, then $P_{\text{max}} = P_{\text{max}}^{\text{charge}}$).

For the last case, the EV is charging using smart charging solutions (like the one proposed in UC2.2), as shown in Figure 39. In this case, the user provided a desired final SoC and a dwelling time. In this case the vehicle will charge its battery with a power $\tilde{P}_{\text{EV}}(t)$ such that $P_{\text{max}}^{\text{release}} \leq \tilde{P}_{\text{EV}}(t) \leq P_{\text{max}}^{\text{charge}}$. It is important to notice that the power $\tilde{P}_{\text{EV}}(t)$ is a stepwise constant as it will be changed every $T'$ sampling time. Given such stepwise constant reference power, the P controller installed inside the charging station acts on the reference power with a sampling time $T' \ll T$ according to a control gain $K_p$, which has to be designed considering the trade-off
between the flexibility of charging power (to contribute to the network frequency regulation), users’ performance and network operations. Moreover, $K_p$ should also depend on the actual charging power that is scheduled for the EV since the EV can absorb up to $P_{max}^{charge}$ and (if V2G is available) can release up to $P_{max}^{release}$.

![Figure 39 Example of the superposition of smart charging and frequency regulation services: (top) network frequency time evolution and (bottom) associated charging session](image)

For sake of simplicity, in the discussion above, we considered a simple Proportional (P) controller without discussing the computation of the gain associated with each charging session. The composition of the different contributions results in the aggregated power-frequency curve, that defines the variation of the charging power as a function of the frequency deviation at the load area level and then the contribution of the load areas to the frequency regulation service. In this use case, we will consider, as a baseline for the quantitative identification of time constraints, the Pilot Project Fast Reserve started by TERNA [14]. The Fast Reserve project focuses on the Frequency Restoration Reserves with Automatic activation (aFRR).

The integration between smart charging, handled in UC2.2, and aFRR service can be faced with different approaches. Nevertheless, the integration must be as much as possible transparent for the end-user (in this context represented by the driver), so aFRR has to consider both aspects related to the quality of the charging sessions and have to guarantee the presence of adequate power margins in order to compose a power-frequency curve satisfying precise property.

There are a lot of technical requirements imposed on the pilot project, but the attention in this context is focused on the power-frequency curve shape, and on how to distribute the frequency regulation effort on each charging vehicle. In the following discussion, two main aspects will be considered:

- The power-frequency curve has to be symmetric, continuous and the actuation has to be self-regulating.
- A dead band may be required to be implemented in the power-frequency curve.

The distribution of the effort can be done considering the smart charging service as a separate service with respect to the frequency regulation one: the smart charging service provides its contribution neglecting the frequency regulation goals. As explained before, the smart charging introduces power margins as side-effect. Referring to the architecture presented in D2.4A, the Master Control Agent has a complete knowledge of the scheduled charging session, as for the power setpoint assigned of each EVSE ($\bar{p}$) and the power limits of the whole charging system. Considering this two information, together with the information about the frequency dead band, the Master Control Agent is able to linearly interpolate, with two separated curves the points
\((\Delta f_{\text{min}}, \bar{p}), (\Delta f_{\text{max}}, p_{\text{max}})\) and \((-\Delta f_{\text{min}}, \bar{p}), (-\Delta f_{\text{max}}, p_{\text{min}})\), where \(\Delta f_{\text{max}}\) and \(\Delta f_{\text{min}}\) characterize the deadband and the frequency deviation over which the EVSEs have to provide the full power margins. The advantages and disadvantages of this approach can be summarized with the following bullet list:

- **Advantages:**
  - the decoupling between smart charging service and aFRR service: the Master Control Agent can be fully agnostic on the smart charging strategy used to compute the setpoint. It only interpolates point in the 2D spaces;
  - the exploitation of all the available margins at the level of EVSE: differently from the next approaches, the EVSE droop curves always intersect the max and min power values.

- **Disadvantages:**
  - the resulting shape of the load area curve: the symmetry requirement for the aggregated power-frequency curve is in general not ensured.

A representative V2G example is shown in Figure 40.

![Figure 28:](image)

Figure 28: Linear interpolation. a) p-f curve of two EVs, b) cumulative p-f curve

The approach presented above doesn’t work together with the smart charging system, but only exploits the margins that are created by side-effect by the smart charging service. Anyway, a different strategy could be considered with a more sophisticated interaction between the smart charging system (UC2.2) and the frequency...
regulation service (UC2.3). The frequency regulation system could control the load area power reference that should be tracked. In UC2.2, it was shown how an external signal is used to drive the aggregated load area power in order to satisfy a DSM service: the same capability could be used to impose a specific aggregated power withdrawal, i.e., half of the nominal power of the active charging sessions present in the load area at the given time. In this condition, the pros and cons of this approach can be summarized as below:

- **Advantages:**
  - applying the linear interpolation strategy presented before, even if at the level of the single EVSE the curves are not symmetric, the aggregate p-f curve satisfies the symmetry requirement.

- **Disadvantages:**
  - the load area should be operated at half of the nominal power capacity;
  - the symmetry is strictly related to the ability of the smart charging system to follow the load area power setpoint.

A representative V2G example is shown in Figure 41 below.

The architecture proposed in D2.4A connects the Master Control Agent to the E-Mobility Platform, as for UC2.2. This design allows to consider a more sophisticated strategy that, instead of simply interpolates fixed points in the frequency-power plane, considers the possibility of developing a resource allocation algorithm, which assigns to each EVSE a specific p-f curve taking into account parameters and information already used for the smart
charging service, e.g., SoC and the dwelling time. The integration of the two services and the use of common parameters can provide a set of droop curves that provide in an aggregated way a load area curve that satisfies the requirement of symmetry while considering drivers' requirements, balancing, and distributing the service provisioning based on user profiling.

The work done for smart charging in UC2.2 can be then considered as preparatory for the activities for frequency regulation, since it provides both the information on the SoC, dwelling time, and the power setpoints. Since the architecture of UC2.3 is compliant with the components of UC2.2, it can benefit of UC2.2 components to provide frequency regulation services and at the same time to provide smart charging services. The advantages and disadvantages of this approach can be summarized with the following bullet list:

- **Advantages:**
  - Effort distribution and profiling.
  - Satisfies the symmetry requirement.
  - Includes drivers’ requirements and improve the transparency of the service.
  - This solution is compliant with the smart charging system proposed in UC2.2.

- **Disadvantages:**
  - Requires an integration with the smart charging system.
  - Requires the design and implementation of resource allocation algorithm.

### 3.3.1.3 Second approach

In this section, we describe an algorithm that intelligently computes local droop curves that are better “customized” for every PEV participating in the provisioning of the frequency control service. Indeed, every PEV in general has a different capability to contribute to frequency regulation, for example due to different inherent technical characteristics (e.g., different battery/power capacity of the PEV), or because perhaps PEVs are performing smart charging sessions characterized by different session parameters (for example, some PEVs might be close to the end of the charging sessions, while other might have just started it; some might have a very high charging power setpoint, while other a very low one, etc.). It is clear therefore that it is of advantage to have an algorithm that computes and allocates tailored droop curves to the single PEVs.

The reference scenario considered in this Section is as follows. At a given time \( k \), a set of \( N \) PEVs is connected to the grid and performing smart charging. The generic \( n \)-th PEV at time \( k \) is characterized by:

- The current charging power level \( P_{n,k} \);
- The maximum and the minimum possible charging power levels, respectively \( P_{\text{max}}^n \) and \( P_{\text{min}}^n \) (if \( P_{\text{min}}^n < 0 \), the PEV is enabled to discharging);
- The current SOC level \( x_{n,k} \);
- The time left until the end of the charging session, \( d_{n,k} \);
- The error, \( e_{n,k} \), between the desired SOC, \( x^{\text{ref}}_n \), and the current one, \( x_{n,k} \);
- The power deviation, \( \Delta P_{n,k} \), at time \( k \), for the \( n \)-th PEV, due to the participation in the frequency regulation service. This value is computed from a droop curve.

The problem we tackle is that of optimally define p-f droop curves at single PEV level (which we call local droop curves in the following), in such a way that, once combined, they match a given, desired droop curve (the global droop curve). The global droop curve defines how, collectively, the connected PEVs should react to frequency mismatches, as if they formed a unique entity participating in the provisioning of the ancillary service.

Therefore, an aspect that is important to stress is that the proposed algorithm is not concerned with the computation of the global droop curve. This curve is an input to the algorithm. The role of the proposed algorithm is to, in a sense, disaggregate the global droop curve into individual ones, each tailored for each PEV participating...
in the frequency regulation service, and computed depending on technical characteristics of the PEV, and also depending on the current status of the PEV’s charging session.

The following figure displays a generic example of a global droop curve, also reporting the definition of the related relevant parameters. In the following, for simplicity, we focus only on the right part of the droop curves, i.e., on the one for positive frequency deviations. We will present an algorithm that disaggregates the global, right-plane droop curve into local, right-plane droop curves. As a matter of fact, the same algorithm, with minimal modifications, can be used to also disaggregate the global, left plane droop curve.

![Figure 42 Global droop curve with associated relevant parameters](image)

The relation between the change of frequency, and the change of power is given by the following expression:

\[ \Delta P(\Delta f) = 0, \text{ for } 0 \leq \Delta f < \Delta f_{\text{min}} \quad (\text{dead band}) \]

\[ \Delta P(\Delta f) = m^{\text{global}} \Delta f + q^{\text{global}}, \text{ for } \Delta f_{\text{min}} \leq \Delta f \leq \Delta f_{\text{max}} \quad (\text{linear droop curve}) \]

\[ \Delta P(\Delta f) = \Delta P_{\text{max}}, \text{ for } \Delta f \geq \Delta f_{\text{max}} \quad (\text{saturation}) \]

The proposed algorithm disaggregates the global droop curve into *linear* local curves. The figure below reports a representation of a generic local droop curve, with relevant related parameters.

![Figure 43 Local droop curve with associated relevant parameters](image)

The generic local droop curve has the following expression.
\[ \Delta P_{n,k}(\Delta f) = m_{n,k} \Delta f + q_{n,k}, \text{for } \Delta f_{\text{min}} \leq \Delta f \leq \Delta f_{\text{max}} \]

\(\Delta P_{n,k}\) denotes the change of the power charging setpoint (with respect to the value determined by the smart charging algorithm) of vehicle \(n\) at time \(k\). Notice that the shape of the local droop curve depends on the parameters \(m_{n,k}\) and \(q_{n,k}\). Therefore, the disaggregation of the global curve in practice corresponds to the computation of \(m_{n,k}\) and \(q_{n,k}\) for every vehicle participating in the frequency control service.

The proposed algorithm is optimization based, and parameters \(m_{n,k}\) and \(q_{n,k}\) are the optimization variables.

In the following, we discuss the constraints and the objective function’s formulation.

**Local droop curve design constraints**

First of all, notice, also by looking at the figure above, that the positive power contribution that a vehicle performing smart charging at power level \(P_{n,k}\) is between 0 (i.e., no contribution, the PEV keeps charging at the level decided by the smart charging algorithm), and \(P_{n,\text{max}} - P_{n,k}\), the maximum possible power increase, given the current charging level \(P_{n,k}\).

With the first constraint, written next, we require that, at \(\Delta f_{\text{min}}\) and at \(\Delta f_{\text{max}}\), the power contribution (“the power delta”) of the generic PEV is between 0 and \(P_{n,\text{max}} - P_{n,k}\):

\[
0 \leq \Delta P_{\text{min}}_{n,k} := m_{n,k} \Delta f_{\text{min}} + q_{n,k} \leq P_{n,\text{max}} - P_{n,k} \\
0 \leq \Delta P_{\text{max}}_{n,k} := m_{n,k} \Delta f_{\text{max}} + q_{n,k} \leq P_{n,\text{max}} - P_{n,k}
\]

With the above constraints, we avoid that the power delta is zero for frequency deviations greater than \(\Delta f_{\text{min}}\), and that it saturates before \(\Delta f_{\text{max}}\).

Aside of being limited by the current charging level, the maximum admissible power delta is also limited by the current SOC of the PEV (hence, by another parameter that depends on smart charging). In fact, consider the limit case of a PEV completely depleted. It cannot contribute any positive power delta to frequency regulation. To take this additional limitation into account, the following constraint is added:

\[
P_{n,k} + \Delta P_{n,k} \leq x_{n,k} \frac{\text{x}_{\text{max}}}{T}.
\]

The above constraint sets that the new charging level, after the addition of the power delta to contribute to the frequency regulation, must be lower than the average charging rate at which the PEV will be fully charged after \(T\) seconds (the sampling time of the local droop curve computation algorithm, i.e., the local curves are updated every \(T\) seconds).

Given the focus on linear droop curves, the above constraints ensure that the contribution of the single PEV is always feasible, also considering the current status of the charging session.

Next, local droop curves must have a positive slope, i.e., \(m_{n,k} \geq 0\). This of course implies also that \(\Delta P_{\text{min}}_{n,k} \leq \Delta P_{\text{max}}_{n,k}\), which is as expected for a frequency droop curve.

Denote now with

\[
\Delta P = m_k \Delta f + q_k, \text{for } \Delta f_{\text{min}} \leq \Delta f \leq \Delta f_{\text{max}}
\]

the droop curve obtained by summing all the local droop curves.

We have that \(m_k = \sum m_{k,n}\) and \(q_k = \sum q_{k,n}\). Therefore, to make sure that the sum of the local droop curves matches the target global droop curve, we have to impose the following constraints:

\[
m_k = m_{\text{global}} \quad \text{and} \quad q_k = q_{\text{global}}.
\]

**Target Function**
There are many ways to select the $N$ local droop curves, so that their sum matches the global droop curve. An optimization criterion can be introduced, to select a preferred disaggregation.

The target function to be minimized by the algorithm is the sum of 5 terms:

$$J_k = \sum_{n=1}^{N} \left[ -\alpha_1 e_k (\Delta P_{\text{min}}_{n,k} + \Delta P_{\text{max}}_{n,k}) + \alpha_2 d_k (\Delta P_{\text{min}}_{n,k} + \Delta P_{\text{max}}_{n,k}) + \alpha_3 m_{\text{max}}_{k} + \alpha_4 \Delta P_{r,k} + \alpha_5 \Delta P_{r,k} \right],$$

where all $\alpha$’s are positive coefficients, $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 = 1$, and $m_{\text{max}}_{k}$, $\Delta P_{r,k}$, and $\Delta P_{r,k}$ are auxiliary variables that define upper bounds, according to the following constraints:

$$m_{n,k} \leq m_{\text{max}}_{k}, \quad \text{and} \quad m_{\text{max}}_{k} \geq 0,$$

$$\frac{\Delta P_{\text{max}}_{n,k}}{p_{\text{max}}_{n,k} - p_{n,k}} \leq \Delta P_{r,k},$$

$$\frac{\Delta P_{\text{min}}_{n,k}}{p_{\text{max}}_{n,k} - p_{n,k}} \leq \Delta P_{r,k}.$$ 

For instance, the first of the above three constraints define $m_{\text{max}}_{k}$ as an upper bound of the local droop curves’ angular coefficients.

The target function has the following interpretation.

The last three terms are aimed at achieving a balanced assignment of the local droop curves, i.e., to avoid unfair allocations where some of them are much steeper or higher than others. This would result in some PEVs having to contribute much more to frequency control, than others. In detail, the third term minimizes the maximum angular coefficient of the local droop curves, while the fourth and the fifth minimize the maximum relative delta power at $\Delta f_{\text{min}}$ and at $\Delta f_{\text{max}}$. In a nutshell, the last three terms are aimed at balancing the frequency regulation effort among the participating PEVs, in an equal way.

The first two terms of the target function instead, are aimed at modifying the droop curves assignment in order to take into account also the current status/progress of the charging session at the different PEVs. In particular, we have to remember that the contribution to frequency control alters the progress of the charging session, since it alters the charging power level. In this sense, it is clever to ask that the PEVs for which a positive contribution to frequency regulation affects positively on the progress of the charging session contribute more than the others to frequency regulation, via the selection of “higher” local droop curves.

For instance, thanks to the first term in the target function, the PEVs associated with a high positive SOC error (i.e., the cars for which the current SOC is far below the reference one) are assigned droop curves which have high values of $\Delta P_{\text{min}}_{n,k}$ and $\Delta P_{\text{max}}_{n,k}$. Therefore, they tend to contribute more to frequency regulation. This is reasonable, since a high contribution helps in reducing the SOC error (since the charging power increases). When the SOC error is negative, the opposite happens.

Thanks to the second term in the target function, the PEVs associated with a very high charging session time, are assigned to “lower” droop curves, to avoid that they are over-exploited by the frequency control service.

Overall, the proposed formulation is linear (notice, also thanks to the use of the H-infinity norm introduced by the last three constraints), which allow the algorithm to scale in an excellent way to very large scenarios.

**Numerical Simulations**

In the following, we present numerical simulations to validate the proposed concept.

We consider two different simulation scenarios:
Scenario 1: a balanced scenario considering a set of charging sessions that are homogeneous in terms of power margin flexibility, SOC error, and charging time availability;

Scenario 2: a scenario in which the charging sessions have different power margins, different SOC errors, and time flexibility.

The two scenarios will thus show that the algorithm performs well both in balanced scenarios, where the regulation effort should be equally distributed among the participant PEVS, as well as in a scenario in which the charging sessions are more heterogeneous, and the regulation effort should be more carefully assigned, to match the specific charging status of the PEVs.

Simulations have been performed in Julia (https://julialang.org/), version 1.6.0, on an standard computer (3.3 GHz, I7 processor with 16 GB RAM). In the simulations, we assume that there are enough active charging sessions in the load area to provide the required power-frequency global curve. This means that the composition algorithm presented in Section 4 admits a solution.

To keep the simulations readable, we will consider a very low number of PEVs. One last simulation will show that the proposed approach scales with no issues over large-scale scenarios.

**Scenario 1**

We consider 3 active charging sessions, with the same dwelling time and SOC error. In a first simulation, the charging sessions are characterized by a maximum charging power of 150 kW, and by the same charging setpoint of 100 kW. This results in a power margin of 50 kW.

Assume that the global droop curve for over frequency is characterized by a maximum power deviation of 105 kW at a frequency deviation of 1500 mHz, and a power deviation of 10 kW for a frequency deviation of 500 mHz.

The following figure shows that the algorithm correctly allocates the same local droop curve to the 3 charging sessions, since they are characterized by the same parameters.

![Figure 44 Scenario 1 - Balanced condition: resulting local and global droop curves](image URL)

The next figure plots the ratio \( \frac{\Delta P_{\text{max}}}{P_{\text{max}} n_{t}, k} \) for every charging session, i.e., the ratio of the PEV contribution to frequency regulation at maximum frequency deviation, over the power margin of the PEV. The plot confirms the equal sharing of the frequency regulation effort among all the PEVs.
In the next simulation, we consider the same charging sessions (with same SOC error and charging session duration), but this time with different power margins for the 3 PEVS, as specified in the following table.

<table>
<thead>
<tr>
<th>PEV ID</th>
<th>$P_{n,k}$ [kW]</th>
<th>$P_{n}^{\text{max}}$ [kW]</th>
<th>$e_{k}$ [%]</th>
<th>$d_{k}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>150</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>100</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>50</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

All the PEVs are charging at 50% of the maximum possible charging level. The maximum value for the global droop curve is taken at 75 kW (i.e., 50% of the available total margin of the PEVs). The local droop curves computed are displayed in the following figure.

Figure 45 Scenario 1 - Balanced conditions: fraction of the maximum PEV power margin used for each PEV

Figure 46 Scenario 1 - Different power margins: resulting local and global droop curves (request of 50% of the overall power margins)
The local curves are different, to take into account the fact that the PEVs have different maximum charging power and different power margins, but, once again, the relative effort is distributed equally among the PEVs, as confirmed by the following figure, since all the PEVs are charging at half of the maximum charging power, and hence have the same relative charging margin.

Figure 47 Scenario 1 - Different power margins: fractions of the maximum PEV power margin used for each PEV (request of 50% of the overall power margins)

Scenario 2

In this second scenario, we test the algorithms in situations in which the charging sessions are characterized by heterogeneous parameters. This is to test the capability of the algorithm to tailor the local curves to the specific boundary conditions of each charging session.

For example, we consider in the following the case in which all the PEVs have the same power levels, but they differ for the SOC error, as detailed in the table below.

<table>
<thead>
<tr>
<th>PEV ID</th>
<th>$P_{n,k}$ [kW]</th>
<th>$P_{n}^{\text{max}}$ [kW]</th>
<th>$e_k$ [%]</th>
<th>$d_k$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>100</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>100</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>100</td>
<td>30</td>
<td>10</td>
</tr>
</tbody>
</table>

The algorithm should put in priority (i.e., assign “higher” and steeper local curves) to the PEVs having large SOC errors.

The resulting local droop curves are reported in the following figure, which confirms the expected behaviour.
The next figure also confirms that PEV 1 and 2 are the ones that contribute more to frequency regulation.

A similar experiment could be carried out also varying the dwelling time, with similar results, confirming that the algorithm can tailor the design of the local droop curves to the conditions specific of each PEV.

Finally, to show that the algorithm can scale to large scenarios, we test the algorithm considering 1000 PEVs participating in the frequency regulation service. The maximum charging levels and the charging session parameters (SOC error and dwelling time) are assigned randomly for each PEV, with values drawn from uniform distributions.
As a result, the local droop curves are also uniformly distributed, as shown in the next figure.

![Figure 50 Simulation with 1000 PEVs](image)

The computing time is below 1.3 seconds. Testing the algorithm on a larger scenario, of 10000 PEVs, the computing time was below 50 seconds, which is still acceptable for real implementation.

Concluding, the proposed algorithm can compose a given global droop curve as the sum of local droop curves, each assigned to a PEV participating in the frequency regulation service. As a result of such smart assignment done by the algorithm, the PEVs participating in the frequency regulation collectively react to frequency imbalances as specified by the global droop curve, assuring proper frequency regulation. Every local curve is computed taking into account the specific technical parameters of the single PEV (e.g., maximum charging power), and also by taking into account the boundary conditions resulting from the specific charging session that each PEV might be undertaking at that moment. In particular, the relevant parameters considered in this case are the SOC error (i.e., the difference between the current SOC and the final desired one), and the time left until the end of the charging session. The consideration of these smart charging session parameters provides a link between the algorithm presented in this section, and the smart charging one (i.e., the one that assigns and periodically recomputes the charging setpoint to each PEV, based on the user preferences on the energy to recharge, and the time available). One notable point is given by the fact that the present algorithm alters the setpoint computed by the smart charging algorithm, hence altering the SOC of the vehicle. However, this disturbance does not pose a problem, since the smart charging algorithm periodically recomputes the charging setpoint, based on the measurements of SOC error, and can therefore adjust the charging setpoint, to close the SOC error introduced by the present algorithm.
3.3.1.4 Detailed sequence diagram

Given the Use Case architecture shown in Figure 36, the detailed message sequence chart for communication among the modules of UC 2.3 is presented here in Figure 51.

In particular, Master Control Agent of Use Case 2.2 (presented in the above sections) may periodically send the computed Power Scheduling from Use Case 2.2 to the Master Control Agent of Use Case 2.3 using the smart_charging_data MQTT topic. Upon the Master Control Agent of Use Case 2.3 receives such message, it computes the Power-Frequency curve (according to the considerations done in the previous sections about the algorithm used) for each Local Control Agent. The Master Control Agent sends the parameter of such Power-Frequency curve for a specific Local Control Agent (that is associated to a Charging Station with EVSEID \{EVSEID\}), using the \{EVSEID\}/pkq MQTT topic. The Local Control Agents store such parameters to be used in case of frequency disturbances to compute the updated power setpoints for their associated Charging Stations.

All what described up to this point happens with the same sampling time of Use Case 2.2 (i.e., 5 minutes or 1 minute), while the next part of the sequence diagram happens with a much smaller sampling time (in the order of 300ms).

Once a frequency measurement is taken by the Frequency Meter (usually each 100ms), it is collected by a IoT Agent (hosed inside the Master Charging Station) via RS232 (envisaged for Test Case 2.3.4) or via ModbusTCP (in Test Case 2.3.2) and forwarded to its associated Local Control Agent using an UDP channel exposed by the Local Control Agent, together with a Measurement ID, that is used for computation of timing and association of an updated power setpoint to the originating frequency disturbance.

Once the Local Control Agent connected to the IoT Agent hosed inside the Master Charging Station receives the frequency measurement, it forwards it to all the Local Control Agents using the frequency MQTT topic if it exceeds the dead band (usually fixed to 50mHz). Once each Local Control Agent receives the frequency measure, it computes the updated power setpoint for its associated IoT Agent / Charging Station using the parameters sent by the Master Control Agent (by a Proportional controller based on the frequency error) and sends back it to its associated IoT Agent using an always-open TCP channel created by the Local Control Agent at the beginning of the experiment. This updated power setpoint contains also the over-mentioned Measurement ID generated by the Master Charging Station’s IoT Agent.

Once the IoT Agent of each Charging Station receives the updated power setpoint from its associated Local Control Agent, it instructs the Power Converter on-board of the Charging Station to change the power setpoint for the charging Electric Vehicle, so that the control action is actuated.
3.3.1.5 **Vertical Service development and integration**

As for UC 2.2, the Vertical Service has been implemented in the 5G EVE platform in order to test and evaluate it in a 5G environment. Therefore, various configurations on the Vertical Service need to take place (see Paragraph 1.1, Section “Vertical Service development and integration”). A set of blueprints and descriptors have been prepared and uploaded in the 5G EVE Platform: VSB, VSB NSD, CTX, CTX NSD, TCB, and EXP NSD.

For the UC 2.3, the Vertical Service has been configured as shown in Figure S2, and the Context Blueprint has been configured similarly to the UC 2.2.

![Figure 52 Vertical Service Blueprint (VSB) for UC 2.3](image)

In particular, all TCs in UC2.3 have been configured as follows:

1. **Atomical functional components (VNF)**
   a. Master_control_agent (mca)
   b. MQTT Broker (mqtt)
   c. Local Control Agent 1 (lca)
   d. Local Control Agent 2 (lca2)

2. **Virtual Link (VL):**
   a. vl_ext_in
   b. vl_data
   c. vl_user
   d. vl_mgmt
   e. vl_eve

3. **Connection Points (CP):**
   a. cp_master_control_agent_user,
   b. cp_master_control_agent_data
   c. cp_master_control_agent_mgmt,
In order to better define the latency components of UC 2.3, a set of different key latencies have been identified, as presented in Figure 53.

In particular:

- time A represents the timespan between the time instant when the frequency measurement is made available by the frequency meter and the time instant when it is sent to the Local Control Agent.
- time B represents the timespan between the time instant when the IoT Agent on-board of the Master Charging Station sends the frequency measurement and the time instant when it is received by the Local Control Agent; this time B is part of the Network latency (RTT).
- time C represents the timespan between the time instant when the Local Control Agent receives the frequency measurement and the time instant when it sends back the power setpoint in response to the frequency deviation event; this time C includes also the time needed by the Local Control Agent to spread the frequency measurement to all the Local Control Agents.
- time D represents the timespan between the time instant when the Local Control Agent sends the updated power setpoint in response to the frequency disturbance event and the time it is received by the IoT Agent (e.g., by the IoT Agent on-board of the Master Charging Station); this time D is part of the Network latency (RTT).
- time E represents the timespan between the time instant when the IoT Agent receives the updated power setpoint and the time instant when the power converter on-board of the Charging Station actuates (at least partially) the new power setpoint.

As stated in D5.2A, the whole control chain (i.e., A+B+C+D+E), plus the time needed by the frequency meter to measure the electricity network frequency, should be less than 300ms (up to the partial actuation of the power...
setpoint due to power converter ramp-up) and 1s (up to the complete actuation of the power setpoint by the power converter).

For this reason, during Cycle 2 activities a new set of KPIs has been defined for Use Case 2.3. These KPIs are again of two types: vertical service KPIs and Network KPIs, and they are presented in the following table:

### Table 14: List of Vertical Service and Network KPIs

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time A</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Time B</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Time C</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Time D</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Time E</td>
<td>Vertical Service</td>
<td>ms</td>
</tr>
<tr>
<td>Power setpoints</td>
<td>Vertical Service</td>
<td>kW</td>
</tr>
<tr>
<td>Power measurements</td>
<td>Vertical Service</td>
<td>kW</td>
</tr>
<tr>
<td>Frequency Measurements</td>
<td>Vertical Service</td>
<td>mHz</td>
</tr>
<tr>
<td>Latency Userplane RTT</td>
<td>Network</td>
<td>ms</td>
</tr>
<tr>
<td>Availability</td>
<td>Network</td>
<td>%</td>
</tr>
<tr>
<td>Reliability</td>
<td>Network</td>
<td>%</td>
</tr>
</tbody>
</table>

Finally, Table 15 shows the list of APIs exposed by 5G-Solutions KPI Visualization System (KPI-VS) that will be tested in Cycle 2. In particular, the **Start Notification** interface is responsible to create a unique session for each test case execution activated on the 5G-Solutions KPI-VS side. The **Vertical Service KPI sending** API is responsible to send the Vertical Service KPIs to the 5G-Solutions KPI-VS. At the end of the test execution, the **Stop Notification** communicates the KPI-VS that test case execution is terminated. The Start/Stop Notifications also provide a (unique) identifier for test case execution (the Experiment ID) to the KPI-VS to filter relevant Network KPIs from 5G EVE facility and to collect the Network KPIs of interest for the Experiment ID associated to the test case execution of interest. The reference implementation of the above-mentioned interfaces can be found in [10].

### Table 15: API list to the 5G-Solutions KPIs VS for TC2.3.3 in Cycle 1

<table>
<thead>
<tr>
<th>Name Interface</th>
<th>Method</th>
<th>URI</th>
<th>KPIs associated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Notification</td>
<td>POST</td>
<td><a href="https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>All Network KPIs (Latency Userplane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
<tr>
<td>Stop Notification</td>
<td>POST</td>
<td><a href="https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification">https://ingress.kpivs-5gsolutions.eu/5gsolutions/data-collector/notification</a></td>
<td>All Network KPIs (Latency Userplane RTT, Availability, Reliability, User Data Rate Downlink, User Data Rate Uplink)</td>
</tr>
</tbody>
</table>
3.3.2 Overview of the Test Setup According to the Plan Described in D2.8 – D2.4A

In this section, the setup activities concerning the energy and the 5G experimental facility are detailed for Cycle 1. The energy facility has been designed and is planned to be fully operative in Q2/2022. The 5G facility has been extended before Cycle 1 specifically to support the use case development.

3.3.2.1 Energy facility setup

The use case Owner (Enel X Way) planned and started the realization of the energy facility to support UC2.3. The facility consists of a set of three traditional EV chargers replacing the JuiceBox 25kW DC as EV charger with 5G connectivity and a frequency regulation meter planned at the beginning. The delay of the development of the three JuiceBox DC (25 kW) has led to a mitigation plan, enacted during Cycle 2, for which Enel X Way will enhance with 5G Communication three Juice2Grid V2G (15 kW) to install together with the frequency regulation meter in Q3/2022. The firmware update allowing to dynamically modify the Frequency – Power curves used to set the operating point of the charger have started in May 2022 and will be ended in Q3/2022 with the integration tests (originally planned for February 2022). The location selected by the use case owner to host the energy facility is the parking area owned by Enel X in the City of Turin depicted in Figure 54.

3.3.2.2 5G facility setup

The 5G facility supporting UC2.3 is the Italian Site of the 5G EVE platform. This Site originally did not cover the energy facility planned by the use case owner (Enel X) in the area selected for the trial activities. In Q2/2020 the Project Consortium asked 5G EVE to extend the current 5G coverage (focused on the so called “Innovation Mile”) to the area selected for the trial activities as shown in Figure 55 where the blue area indicates the site for trial activities in UC2.3 while the yellow one the target area (Innovation Mile) covered by the 5G EVE platform.
In Q2/2020, the 5G EVE facility has been extended to guarantee suitable coverage for trial activities of UC2.3 for Cycle 1. During Cycle 1, the coverage provided by the 5G facility has been tested by the 5G Site Manager (TIM) and Use Case Developer (Ares2t). Raw network indicators have been collected in the site for trial activities as part of the 5G facility set up activity. These indicators provided a consolidated basis for design and development activities of the software components of the use case architecture though the facility presents a potentially criticality since the 5G coverage that was successfully tested in the energy facility during Cycle 1 (January 2021) could be not present anymore, as happened to UC 2.2 during Cycle 2 (from June 2022 on).

Though the physical infrastructure of the 5G EVE facility was setup and available, the 5G EVE platform supporting the Use Case 2.3 was not fully operating from February 2022 on. Consequently, during the execution of test cases TC2.1.1 and TC2.1.3 there was no mean:

1) to dynamically deploy the necessary VNF chain  
2) to schedule any test case execution  
3) to integrate the 5G-Solutions CDSO via 5G EVE north-bound APIs  
4) to communicate Network KPIs to the KPI Visualization System

For this reason, in the execution of test cases reported in the following,

1) the VNF chain has been deployed manually,  
2) there was no schedule through the 5G EVE web portal,  
3) there was no trial with CDSO  
4) it was not possible to collect the Network KPIs by the KPI Visualization System.

### 3.3.3 Execution of Test Case TC2.3.1

Test Case 2.3.1 aims at testing the control infrastructure, as depicted in Figure 56, in order to validate the software modules that computes the power-frequency curve for each charging session and the software modules that communicate with the IoT Agents of the Charging Stations both the frequency measure (that in this Test Case comes from synthetic data) and the updated frequency-dependent power setpoint for the charging session happening on the Charging Station.

Test Case 2.3.1 includes the Master Control Agent software module, that is different from the Master Control Agent of Use Case 2.2, and it is meant to compute the power-frequency curves for the Local Control Agents (e.g., based on the power schedule computed by Use Case 2.2), the Local Control Agents (one for each Charging Station...
- IoT Agent to be controlled), that, receiving the frequency measurements from the IoT Agent of the Master Charging Station, and spreading to all the other Local Control Agents, compute the updated frequency-dependent power setpoint for the Charging Stations based on the power-frequency curves computed by the Master Control Agent.

For Test Case 2.3.1, Master Control Agent makes use of the first approach described in Section 3.3.1.2 to compute the power-frequency curve parameters for each charging Electric Vehicle.

Master Control Agent and Local Control Agents communicate each other using MQTT protocol, so the MQTT Broker ensures the messages are exchanged among the software agents.

For this Test Case, the IoT Agents software modules are emulated, since the actual IoT Agents software modules are to be installed in Cycle 3 inside the Enel X Way Charging Stations. In any case, the interface between emulated/real IoT Agents and Local Control Agent will basically remain the same in Cycle 3 Test Cases. This opens the possibility to validate the whole architecture (in a preliminary way) even if the Charging Station and the Frequency Meter are still not present on the field.

The communication between Local Control Agents and IoT Agents happens via UDP and TCP over 5G communication technology, according to the detailed message sequence chart presented above.

3.3.3.1 Purpose of the Test

The purpose of Test Case 2.3.1 is to validate the control loop for frequency regulation by using synthetic data for frequency measurements and emulated IoT Agents / Charging Stations. This will preliminarily demonstrate that the proposed approach is viable by using 5G technologies in terms of control loop delay, that must be kept lower than 300 ms, as defined by the Italian Transmission System Operator (TERNA) in order to participate to frequency regulation services.

Subsequent test cases will incrementally substitute the synthetic frequency measures with real measures from a Frequency Meter and emulated IoT Agents / Charging Stations with their real counterparts.

3.3.3.2 Test Setup

All the test for Test Case 2.3.1 will be performed in IREN premises in lab environment, since at the moment no actual Charging Station or electric load or frequency meter is envisaged for this Test Case.

Test Case 2.3.1 involves the following hardware components:

- Huawei CPE 5G modem (see Figure 14)
● Laptop connected via ethernet cable to the 5G modem and running emulated IoT Agents
● CDSO integrated with the 5G EVE facility
● The full VNF chain deployed
  o Delay Generator as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  o Master Control Agent as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  o MQTT Broker as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
  o Local Control Agents, each one as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
● 5G Solutions KPI- VS through the suitable interfaces defined in the use case implementation and integration activities.

As the 5G modem is connected to the 5G EVE APN, the Master Control Agent and the Local Control Agents are ready, the emulated IoT agents are running the test is ready to be run. Once the CDSO starts the execution, all the VNFs are instantiated in 5G EVE MEC, and the execution of the test begins.

3.3.3.3 Challenges
The main challenges for Test Case 2.3.1 are:
● Test the delay of the frequency regulation control loop to be lower than 300ms (included estimated time needed by the frequency meter to measure the electricity network frequency)
● Test the deployment of the software modules of Figure 56 inside 5G EVE VNFs.

3.3.3.4 Planned Execution
Test Case 2.3.1 is planned to be executed using particular shapes for frequency disturbance events: in particular the disturbances are modelled as:
● square wave between 49.5Hz and 50.5Hz
● saw-tooth wave between 49.5Hz and 50.5Hz
● gaussian noise between 49.5Hz and 50.5Hz

In this way it will be possible to notice the reaction of the control architecture to dead band (set to 50mHz) and to high-amplitude frequency disturbances. In May 2022 the test case TC2.3.1 has been successfully executed with 5G in line with the planned execution (reported in D2.4B).

3.3.4 Execution of Test Case TC2.3.2
Test Case 2.3.2 is built on top of Test Case 2.3.1 as it includes the same software components of Test Case 2.3.1, except for the frequency meter, that is simulated (as the other hardware components of UC 2.3, like Charging Stations, IoT Agents and Electric Vehicles) in Test Case 2.3.1, while it is a real hardware component in Test Case 2.3.2. This also means that all the KPIs that could be collected in Test Case 2.3.1 are also present in Test Case 2.3.2. Moreover, Test Case 2.3.2 faces all the issues related to measurement timing and interfacing with the frequency meter, that should be taken into account in order to demonstrate that the proposed goal of 300ms is actually viable using 5G technologies.

For Test Case 2.3.2 a Gobmaier micromax-f frequency meter (represented in Figure 58) has been used. This frequency meter is the same that will be utilized in subsequent Test Cases for Use Case 2.3. This frequency meter has been chosen because of its measurement time; indeed, most of the frequency meters on the market take a frequency measure each second, while the Gobmaier micromax-f is able to take a frequency measure each second with accuracy +/- 1mHz or each 100ms with accuracy of +/- 5mHz, that is in line with the requirements of
the Italian Transmission System Operator (TERNA). Moreover, it can transmit the frequency measurement via RS232, ModbusTCP, UDP and TCP (via XML messages).

Also for Test Case 2.3.2, Master Control Agent makes use of the first approach described in Section 3.3.1.2 to compute the power-frequency curve parameters for each charging Electric Vehicle.

In Test Case 2.3.2 the IoT Agents software modules are emulated, since the actual IoT Agents software modules are to be installed (in Cycle 3 Test Cases) inside the Enel X Way Charging Stations.

The communication between Local Control Agents and IoT Agents still happens via UDP and TCP over 5G communication technology, according to the detailed message sequence chart presented above. The communication between Gobmaier micromax-f and the IoT Agent connected to it happens using ModbusTCP via LAN.

![Test Case 2.3.2 deployment architecture](image)

### 3.3.4.1 Purpose of the Test

The purpose of Test Case 2.3.2 is to validate the proposed approach for frequency regulation by integrating a real frequency meter inside the control architecture. In such a way it is possible to demonstrate that the proposed architecture works with the expected KPIs (and in particular the ones related to control loop delays) even in presence of real measurement hardware. Moreover, it validates also the proposed algorithm with real data, instead of simulated ones.

### 3.3.4.2 Test Setup

All the test for Test Case 2.3.2 has been performed in lab environment in the Ares2t premise in the City of Turin, since in Cycle 2 no actual Charging Station or electric load is envisaged for this Test Case in the considered test field (as reported in the Section 3.3.2.1).

Test Case 2.3.2 involves the following hardware components:

- Huawei CPE 5G modem
- Gobmaier micromax-f Frequency Meter connected via ethernet cable to the 5G modem
- Laptop connected via ethernet cable to the 5G modem and running emulated IoT Agents
- CDSO integrated with the 5G EVE facility
- The full VNF chain:
- Delay Generator as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
- Master Control Agent as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
- MQTT Broker as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
- Local Control Agents, each one as VNF deployed on the 5G EVE facility and integrated in the VNF chain configured by the Vertical Service
- 5G Solutions KPI-VS through the suitable interfaces defined in the use case implementation and integration activities.

Once the 5G modem is connected to the 5G EVE APN, the Master Control Agent and the Local Control Agents are ready, the emulated IoT agents are running and collecting measures from the Frequency Meter, the test is ready to be run. Once the CDSO starts the execution, all the VNFs are instantiated in 5G EVE MEC, and the execution of the test begins.

3.3.4.3 **Challenges**

The main challenges for Test Case 2.3.2 are:

- Test the Gobmaier micromax-f Frequency Meter and its interface with the emulated IoT Agent
- Test the interface between emulated IoT Agent and Local Control Agent both for communication of frequency measurements and for communication of updated power setpoints.
- Test the delay of the whole control loop, ensuring it is lower than 300ms, while also analyzing the various components of the measured delay (times A, B, C, D and E).

3.3.4.4 **Planned Execution**

Two sets of tests are planned for the execution of Test Case 2.3.2:
● a first set of tests, used to validate the delays of the control loop and the interfaces with reduced dead band to 1-10 mHz, to make the control action happen more frequently (indeed, electricity network frequency is often in the range 49.99Hz - 50.01Hz)
● a second set of tests, used to validate the Test Case in a more realistic environment, i.e., with dead band of 50 mHz, as prescribed by the Italian Transmission System Operator (TERNA); in this case we expect much fewer activations of the control loop, since it is quite uncommon to the electricity network frequency to be <49.95Hz or >50.05Hz

It is important to notice that, even running the experiments with reduced dead band, this does not influence the other KPIs (like the measured delays) or the performance of the whole Test Case. In May 2022 the test case TC2.3.2 has been successfully executed with 5G in line with the planned execution (reported in D2.4B).

3.3.5 Effect of the COVID

COVID pandemic situation affected UC2.3 setup and execution in trials of the first part of Cycle 2. Nevertheless, as described above, the partners collaborated in the integration and deployment activities to set up the test case execution and the test cases planned for Cycle 2 (TC 2.3.1 and 2.3.2) have been successfully executed with 5G according to the plan.

3.3.6 Mitigation Measures

Mitigation measures from Cycle 1 have been considered in Cycle 2 and no update has been necessary since the test cases planned for Cycle 2 (TC 2.3.1 and 2.3.2) have been successfully executed with 5G according to the plan. Mitigation measures are related to the energy facility as it is not completely set up yet and the possibility to test the complete end-to-end communication with a partially setup is under discussion.

3.3.7 Next Steps

Through the experience in trialing TC2.3.1 and 2.3.2, we gained a lot of information to support the development of the remaining test cases TC2.3.3 and 2.3.4 planned for Cycle 3 and to improve the Vertical Service KPIs in terms of overall test performance in Cycle 3, where the execution of all the integrated use case 2.3 is planned.
4 LL3 – Smart city and ports

Due to the “Demonstration” nature of this deliverable, LL3 decided to provide the documentation of LL3 trials though videos, available at the link https://drive.google.com/drive/folders/1PtkIltqxMovj1e1TbliQA4A02Xfq0T?usp=sharing
5 Conclusions and Next Actions

This deliverable is intended to demonstrate the field trials that has been conducted in Cycle 2 in the Living Lab Smart Energy. In line with the seminal use case analysis and related requirements reported in D1.1A and updated in D1.1B, the document brings together the use case design and descriptions defined in D2.4A (and recently updated in D2.4B) and the use case implementation, deployment and technical validation via trials accomplished in Cycle 2 in the different testbeds.

In the Living Lab Smart Energy (LL2), three use cases have been proposed, analysed from the technical and business point of view in D1.1A and D1.1B, planned and presented from the technical point of view as per D2.4A and D2.4B (including high level architecture and the most relevant sequence diagrams), and initially developed in Cycle 1 with a few recommendations for test case execution in Cycle 2. The status of the development of each use case depends on the following conditions.

- **The status of implementation, deployment and integration of the hardware and software components**
  - UC2.1 – **Industrial Demand Side Management** presents a consolidated architectural design and a good status of deployment and integration of the hardware and software components. In line with lesson learned in Cycle 1 and related recommendation, architectural components have been revised. Two test cases (TC2.1.1 and TC2.1.3) out of three have been completely integrated as reported in Section 3.1.1, 3.1.3 and 3.1.4
  - UC2.2 – **Electrical Vehicle (EV) Smart Charging** presents a consolidated architectural design and a good status of deployment and integration of the hardware and software components. In line with lesson learned in Cycle 1, architectural components have been revised. Two test cases (TC2.2.4 and TC2.2.6) out of six have been completely integrated as reported in Section 3.2.1, 3.2.3 and 3.2.4
  - UC2.3 – **Electricity network frequency stability** presents a consolidated architectural design and a preliminary status of deployment and integration of the hardware and software components in line with lab test executed in Cycle 1. The main architectural components have been implemented and deployed as described in Section 3.3. Two test cases (TC2.3.1 and TC2.3.2) out of four have been completely integrated as reported in Section 3.3.1, 3.3.3 and 3.3.4

- **The energy facility and equipment readiness**, since each test site requires suitable energy equipment provisioning according to the goal of each test case execution
  - UC2.1 – **Industrial Demand Side Management** presents good status of the energy facility consisting of a Heat Pump remotely controlled by 5G connectivity by the UC Owner (Iren). The energy facility has been completely set up and supported the test case executions as reported in Section 3.1.2.1
  - UC2.2 – **Electrical Vehicle (EV) Smart Charging** presents good status of the energy facility consisting of an Electric Vehicle Charger (Alfen 22kW AC) integrated with 5G connectivity modem by the UC Owner (Iren). The energy facility has been completely set up and supported the test case executions. Further deployment activities are planned the Vertical partner (Enel X Way) to install three Juice2Grid V2G stations (15 kW) integrated with 5G connectivity modem by July 2022 (to be ready in Cycle 3), as reported in Section 3.2.2.1
  - UC2.3 – **Electricity network frequency stability** presents a preliminary status of the energy facility integrating the basic facility setup for smart charging in UC2.2 with a frequency regulation meter that will be installed in the facility by the UC Owner (Enel X Way) starting from Cycle 3, as reported in Section 3.3.2.1

- **The 5G facility readiness**, in this case the Italian Site of the experimental platform 5G EVE, with all the active services offered by the 5G EVE platform: though due to a temporary unavailability of the 5G EVE
platform some functionalities of the 5G facility were not available in Cycle 2 (starting on February 2022). Therefore in all test case execution the following issues were experienced: i) no dynamic deployment of the VNF chain (this task required a manual configuration of the VNFs from static VM); ii) no schedule or status about the experiment execution were available (no specific test case configuration was possible via the 5G EVE web portal); iii) no integration of the Vertical Service with the 5G-Solutions CDSO via 5G EVE north-bound APIs was possible in Cycle 1 (the integration with CDSO was successfully trialed in Cycle 1); iv) no Network KPIs have been communicated to the KPI Visualization System by the 5G EVE platform in Cycle 2 (the integration with KPI Visualization System was successfully trialed in Cycle 1). Nonetheless, the status of the 5G physical infrastructure made possible the executions of the test cases in Cycle 2 as follows.

- **UC2.1 – Industrial Demand Side Management** presents an acceptable status of the 5G facility set up for RAN coverage and configured to support the communication between the end points in the two test cases TC2.1.1 and TC2.1.3, as reported in Section 3.1.2.2
- **UC2.2 – Electrical Vehicle (EV) Smart Charging** presents a critical status of the 5G facility in Cycle 2 due to fact that the 5G coverage that was successfully tested in the energy facility during Cycle 1 (January 2021) was not present at all during Cycle 2 (from June 2022 on). Therefore, though the 5G equipment in the test field is correctly configured to support the 5G communication between the end points in the two test cases TC2.2.4 and TC2.2.6, these test cases have been executed with 4G+ instead of 5G in Cycle 2, as reported in Section 3.2.2.2
- **UC2.3 – Electricity network frequency stability** presents a status of the 5G facility being not completely ready since an extension would be necessary in Cycle 3 for the connectivity between the Vertical Service deployed in the 5G facility and the E-Mobility Platform by the UC Owner (Enel X Way). Nonetheless, the test cases TC2.3.1 and TC2.3.2 have been executed in Cycle 2: the former with 4G+, the latter with 5G, as reported in Section 3.3.2.2

- The integration of the Vertical Service with the 5G-Solutions Cross Domain Service Orchestrator (CDSO) and KPI Visualization System (KPI VS) developed in this project by technological partners in WP2 and WP3, respectively, with the support of the Vertical Service Developer (Ares2t)
  - **UC2.1 – Industrial Demand Side Management** The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has been successfully tested in Cycle 1 but has not been trialed in Cycle 2 because of the issues affecting the 5G EVE platform. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the three test cases (TC2.1.1, TC2.1.2 and TC2.1.3). All Vertical KPIs from TC2.1.1 and TC2.1.3 trialed in Cycle 2 have been collected by KPI-VS. No network KPI was collected by the 5G EVE platform, as reported in Section 3.1.2.2
  - **UC2.2 – Electrical Vehicle (EV) Smart Charging** The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has been successfully tested in Cycle 1 but has not been trialed in Cycle 2 because of the issues affecting the 5G EVE platform. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the three test cases (TC2.2.3, TC2.2.4 and TC2.2.6). All Vertical KPIs from TC2.2.4 and TC2.2.6 trialed in Cycle 2 have been collected by KPI-VS. No network KPI was collected by the 5G EVE platform, as reported in Section 3.2.2.2
  - **UC2.3 – Electricity network frequency stability** The integration of the Vertical Services with the 5G-Solutions Cross-Domain Service Orchestrator (CDSO) has not tested yet and is re-planned to Cycle 3 due to the temporary unavailability of the 5G EVE platform. The integration of the Vertical Services with the 5G-Solutions KPI Visualization System (KPI-VS) has been successfully completed for the test cases TC2.3.1 and TC2.3.2: though network KPIs were not collected by the 5G EVE platform, all Vertical KPIs from TC2.3.1 and TC2.3.2 trialed in Cycle 2 have been collected by KPI-VS as described in Section 3.3.3
The suitable deployment of the Vertical Service as one chain of atomic VNFs in the 5G facility through the 5G EVE platform via web interfaces and portal.

- **UC2.1 – Industrial Demand Side Management** The deployment of the Vertical Service for two test case planned for Cycle 2 (TC2.1.1 and TC2.1.3) has been completed to run the necessary integration test with **two VNF chains**: the chain of one VNF (Experiment Server) for the former (TC2.1.1) and two VNFs (Remote Controller and Delay Generator) for the latter (TC2.1.3).

- **UC2.2 – Electrical Vehicle (EV) Smart Charging** The deployment of the Vertical Service for two test case planned for Cycle 2 (TC2.2.4 and TC2.2.6) has been completed to run the necessary integration test with **one VNF chain**: the chain of three VNFs (Charge Advisor, Master Control Agent and MQTT Broker) supporting TC2.2.4 and TC2.2.6.

- **UC2.3 – Electricity network frequency stability** The deployment of the Vertical Service for the test case 2.3.1 and 2.3.2 planned for Cycle 2 has been completed to run the necessary integration test with **one VNF chain**: the chain of four VNFs (Master Control Agent, MQTT Broker and two Local Control Agents) supporting TC2.3.1 and TC2.3.2.

The three use cases in LL2 presents a different status of development according to the above-mentioned five key conditions and the actual situation is described in Sections 3. Next actions concern the integration activities related to test cases planned for Cycle 2 and related execution in Cycle 3 gaining experience through the analysis of results and lessons learned reported in deliverable 5.3B.
6 References

[1] 5G-Solutions project. D1.1 “D1.1A - Definition and analysis of use cases/scenarios and corresponding KPIs based on LLs (v1.0)”, September 2021.


[16] 5G-Solutions project. D1.1 “D1.1B - Definition and analysis of use cases/scenarios and corresponding KPIs based on LLs (v2.0)”, May 2022.

