5G Solutions for European Citizens

D2.4A: LLs planning, setup, operational management handbook (initial version)

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1 month after the Task started: Deliverable outline and structure
3 months before Deliverable's Due Date: 50% should be complete
2 months before Deliverable's Due Date: 80% should be complete
1 months before Deliverable's Due Date: close to 100%. At this stage it sent for review by 2 peer reviewers
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Glossary of terms and abbreviations used

Abbreviation / Term	Description
API	Application Programming Interface
AR	Augmented Reality
BMS	Building Management System (in LL2)
CDSO	Cross Domain Service Orchestrator
CDN	Content Delivery Network
CSP	Control Service Provider (in LL2)
DCS	Distributed Control System (in LL1)
DLC	Digital Lean Container (in LL4)
DM	Dispatching Market (in LL2)
DSM	Demand Side Management (in LL2)
E2E	End To End
GIS	Geographic Information System
gRPC	Google Remote Procedure Call (in LL1)
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technologies
IoT	Internet of Things
KPI	Key Performance Indicator
LL	Living Lab
MEC	Multi-access Edge Computing
MES	Manufacturing Execution System (in LL1)
MVA	Million Volt-Amps
NGA	Next Generation Access
NOP	Network Operator
PDCA	Plan-Do-Check-Act
PDSA	Plan-Do-Study-Act
PLC	Programmable Logic Controllers (in LL1)
PLC	Power Line Communication (in LL2)
PoC	Proof of Concept
RC	Remote Controller (in LL2)
RMCU	Remote Monitoring and Control Unit (in LL2)
RPC	Remote Procedure Call (in LL1)
RSRP	Reference Signals Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received signal strength indication
RSSNR	Reference Signal Signal to Noise Ratio
RTU	Remote Terminal Unit (in LL2)
TC	Test Case
TMC	Technical Management and Coordination
TSO	Transmission System Operator (in LL2)
UC	Use Case
UCS	Use Case Stakeholder

UC-S	Use Case Scenario
UHD	Ultra High Definition
UHFM	Ultra High-Fidelity Media
VNF	Virtual Network Function
VPP	Virtual Power Plant (in LL2)
VS	Visualization System
WSN	Wireless Sensor Network

1. Executive Summary

The scope of this document is to describe in detail the Use Case planning for Cycle 1 and, where suitable, the complete plan for work breakdown structure of Use Cases with respect to related objectives and activities.

Following a systematic approach and taking into account feasibility and progressive service installation, **14 out of 20 use cases were selected to participate in Cycle 1 trials**. The selected use cases represent adequately all Living Labs 1-4 and they aim at providing significant experience toward installing services on the testbeds, implementing the necessary VNFs and liaising with the CDSO and the Visualization System. These trials and the associated measurements will pave the way towards acquiring adequate experience and insights for the deployment of all UCs in the forthcoming Cycles.

To maintain consistency of the descriptions **the following information is detailed in each if the selected for Cycle1 trials Use Cases**:

- *the objective and the design*
- *the plan*
- *the reference architecture*
- *the interfaces to the Orchestrator and the KPIs Visualization System*
- *the set of test cases*
- *the target KPIs*

It is important to note that, although significant efforts have been made in order to evolve each Use Case towards a mature understanding of it, **two of them (i.e. UC3.1 and UC3.2)**[2] will still be implemented as "best effort" within Cycle 1 trials, due to their complexity and extremely challenging aims from both research and commercial points of view.

In addition, the deployment of most of the Use Cases has been impacted by the COVID-19 lockdown in terms of accessing the physical testbed infrastructures (offered by third parties, e.g. ICT 17 projects) and receiving appropriate equipment (e.g., 5G modems and terminals). To this end, the plans presented in this deliverable may need to adapt to cope with emerging and evolving situations.

In deliverable D2.8-D2.4A the management and monitoring tasks are detailed for each Use Case. The objective of these tasks is to report the test-bench to the stakeholders, so as to be able to demonstrate through actual field trials.

The Use Cases are grouped in Living Labs (LLs). The process of developing the LLs and their Use Cases will be agile, so that a constant interactive cycle of progress will be delivering the results incrementally as services. To this end, the LLs will be following the "Deming Cycle" based on the paradigm *Plan–Do–Check–Act* (see Section 3.1). There will also be feedback from the LLs towards the research activities.

[2] In the best effort UCs the Test Cases are not defined.

2. Introduction

The 5G-SOLUTIONS roadmap follows the 3GPP, the IMT-2020 and the 5G-PPP implementation roadmaps according to the evolution and upgrades of the 5G EVE and 5G-VINNI ICT-17 facilities as depicted in Figure 1. This is achieved through 3 iterative and consequential testing cycles in Phase 3 each lasting for 6 months (Cycle 1, Cycle 2 and Cycle 3), followed by an evaluation period of two months to ensure the smooth and aligned evolution of the vertical industry validations in the Living Labs.

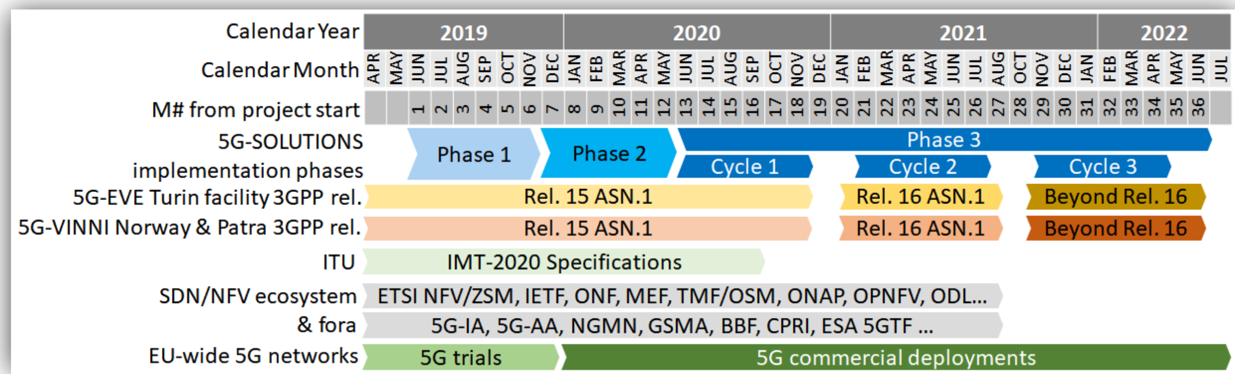

Figure 1: 5G-SOLUTIONS trials roadmap

Following Phase 1 completion, in Phase 2 the focus was placed on the selection of the most mature Use Cases to be included in Cycle 1 trials. Evaluation was based on the possibility of each UC to provide:

- a detailed architecture and information flow diagram, including testbed components and software elements,
- Cross Domain Service Orchestrator (CDSO) and 5G facility orchestration requirements
- Visualization System (VS) requirements

The Use Cases selected for Cycle 1 trials and their status with respect to COVID-19 impact is detailed in Table 1.

Table 1: Use Cases selected for Cycle 1 trials

UC	UC Title	UC planning status	COVID-19 impact
1.1	Time-critical process optimization inside digital factories		
1.2	Non-time-critical communication inside factories		
1.3	Remotely controlling digital factories		
1.4	Connected goods		
1.5	Rapid deployment, auto/re-configuration, testing of new robots		
2.1	Industrial Demand Side Management		
2.2	Electrical Vehicle Smart Charging		
2.3	Electricity Network Frequency Stability		
3.1	Intelligent Street Lighting		
3.2	Smart Parking		
3.3	Smart city co-creation		
3.4	Smart buildings / Smart campus		
3.5	Autonomous assets and logistics for smart harbour/port		
3.6	Port Safety: monitor & detect irregular sounds		

4.1	Ultra High-Fidelity Media		
4.2	Multi CDN selection		
4.3	On-site Live Event Experience		
4.4	User & Machine Generated Content		
4.5	Immersive and Integrated Media and Gaming		
4.6	Cooperative Media Production		

Legends:

UC planning status	Color
On track	
Partially on track (Simplified/Best effort)	
Not in scope for Cycle 1	

UC Covid-19 impact	Color
Medium (Remote or partial access to testbed)	
High (limited or no access to testbed, delay in receiving equipment)	
Not in scope for Cycle 1	

2.1 Mapping Projects' Outputs

The purpose of this section is to map 5G-SOLUTIONS Grant Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed. This is shown in Table 2.

Table 2: Adherence to 5G-SOLUTIONS GA Deliverable & Tasks Descriptions

Project GA Component Title	Project GA Component Outline	Respective Document Chapter(s)	Justification
TASKS			
Task 2.5 - LLs planning, setup, operational management and evaluation	*This is the management and monitoring task whose objective is to report the test-bench to the stakeholders, so as to be able to demonstrate through actual field trials that the underlying 5G ICT-17 facilities are capable of supporting the stringent KPI requirements needed for the successful delivery of innovative vertical services that require 5G performance capabilities. The process in developing the LLs and their use cases will be agile, so that a constant interaction cycle of progress will be delivering the results incrementally as services. To this end, the LLs will be following the Deming Plan – Do – Check – Act cycle. There will be a*	*Section 3, Section 4, Section 5*	Section 3 analyses the UCS deployment methodology according to the DOA. Section 4 maps the UCs selected for the Cycle 1 trials to the respective testbeds. Section 5 analyses for each individual UC the architecture, the information flow, the requirements towards the testbeds, the orchestration and the visualization system and the test cases.

	constant interplay between the LLs' progress and the research developments. Each Living Lab (LL) will contribute in providing the overall planning as well as the setup activities for the deployment and testing of the use cases in the Living Lab. Prepare the evaluation of the LLs, including indications on the baseline conditions (in terms of criteria for defining the sample), relevant assumptions to be considered (if any), workflow, checklists and templates, reference/target KPIs to be met/benchmarked according to deliverable D1.1, and key roles and interactions within this process. Particular attention will be dedicated to the planning phase by defining a Gantt chart of the expected tests, analysis and feedbacks loops before the final delivery of the evidence form the LLs. Once this procedure is structured, and before actually implementing it, it will be presented to and validated with all relevant partners in order to check its feasibility and maximize its efficiency. This task focuses on reporting and integrating the achievement resulting from the execution of each LL. *This task includes also the monitoring phase, which will allow the project staff to take stock of relevant data, define datasets for impact analysis, process and collect measurements, and organize outcomes into actionable information. The results generated will be compared to the reference target KPIs to assess the performance of the 5G network, provide feedback for refinements and, eventually, final recommendations, which will be fed to the evaluation and lessons learned tasks. The leader of this task will also monitor the implementation progress of the execution of the use cases, in coordination with the LLs leaders and the WP1, WP2, WP3 and WP4 leaders to guarantee the compliance with the project objectives. The leader of this task is not responsible of the execution of the LLs and their UCs, as well as of the results*		

	at the end of each cycle.		
DELIVERABLE			
D2.4A: LLs planning, setup, operational management handbook (initial version) *The deliverables (initial and final versions) contain the implementation results and testing plan for the operation of all Living Labs, integrated from independent contributions from the LL leaders and updated at the end of each iterative testing cycle period, providing reporting on progress made.*			

2.2 Deliverable Overview and Report Structure

A consistent methodology is required to plan, deploy and operate fourteen parallel UCs in a wide variety of distant testbeds. To this end, Section 3 of this deliverable describes the overall methodology aiming at setting a consolidated basis for the detailed trails analysis, development and deployments. Section 4 outlines the testbeds that are going to be used for the UCs deployment while Section 5 contains detailed description of each individual UC in terms of architecture, information flow, activities planning, requirements for the testbeds, Orchestration and Visualization Systems, and KPIs to be measured.

3. Trials planning and monitoring method

The ultimate purpose of the Living Labs is to generate a common framework for the validation of the capabilities and the 5G technologies across different Use Cases in the same Living Lab. As such, the validation of the capabilities is intended to address both the technology and the business aspects.

In order to measure and evaluate the technological and business impact introduced by each one of the three cycles in the context of each Use Case, a three-stage testing practice has been proposed. For the sake of clarity, the different actors taking part or having a specific role in each phase have been organized into two groups. The first group called *Technical Management and Coordination* (TMC) includes all the partners involved in technical management, orchestration, technology providers, the responsible for the underlying ICT-17 facilities, and the Living Lab leaders. The second group includes Use Cases owners and stakeholders involved in the execution of the Use Case and are called *Use Case Stakeholder* (UCS). Both groups take part to the three stages, though performing different tasks in close interaction within each other.

Figure 2 summarizes the three stages and the main tasks foreseen in each stage, as described in the following.

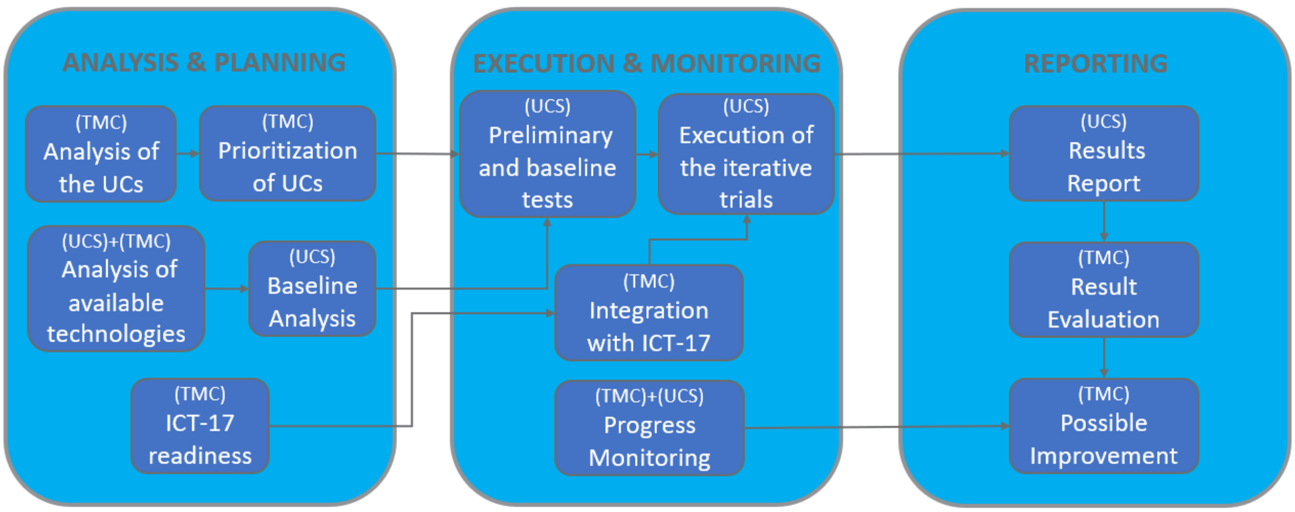

Figure 2: Schematic Representation of the Three-Stage Testing Practice

The first of the three stages to be executed is the **Analysis and Planning** stage. In this stage, all Use Cases are analyzed by the TMC team under different perspectives including (but not limited to) the degree of definition, the technology readiness, the potential business impact, with the aim of prioritizing some of the Use Cases, also considering potential inter-dependencies. Together with the support of TMC, the UCS team will perform an analysis of the available technologies that suit the Use Cases to set a baseline on top of which to perform the actual trials. To conclude this first stage, the TMC will work on the underlying ICT-17 facilities to perform the integration with the Use Cases that are supposed to run on one of the two available facilities.

The second stage, named **Execution and Monitoring,** includes the execution and monitoring of the Use Case trial. Before jumping into the actual execution of the trial, a series of preliminary baseline tests can be conducted for those Use Cases that can benefit from that. This is quite important for the industrial Use Cases, where the equipment, the 5G private node and the infrastructure necessary to run the test have to be installed into a production plant that cannot easily be stopped (or delayed) without impacting operation as well as incurring in economic losses. In such a situation, it is beneficial for the Use Case to perform preliminary tests in a dedicated and protected location (with a fully dedicated 5G infrastructure) simulating the implementation environment as much as possible in order to minimize the risk of failure or impacting the operation. After this preliminary step, the Use Case trial can be executed as planned, performing all the test cases necessary to support the technology and business KPIs validation. In parallel, the TMC and UCS teams will continuously monitor the execution and the progress of the Use Case trials, availing of reference methodologies and common templates for the technology and business validation.

In preparation for this second stage, a set of initial test cases have been designed and integrated to this deliverable for the UCs in their respective TC Design section using a set of templates provided in D1.4A as per the Testing Methodology and Formalization. The aim is to derive gradually the test cases from the use cases using a common format to all LLs while taking into account their specificities.

First it requires the definition and extraction of the test scenarios: describing the conditions at an application level, network level (i.e. network slice). Secondly the selected test areas are described: representing the different segments of UC Architecture with associated test levels until end-to-end coverage is achieved. The final step for this phase is the elaboration of the test cases and is depicted using a Matrix where one or more: test area, test scenario and KPI to be validated are combined to form a test case.

As we progress through the trials: the test cases will be further specified, reviewed and updated using the formalisation and modularisation methods and will be included as part of a final report.

Finally, the third and last stage, named **Reporting**, consists of creating a complete report of the experiment that will feed the official project deliverables and/or the TMC evaluation templates in order to get insights on future improvements for the following cycles of the project. The report will include technical and business assessment of results from field trial with respect to initial aims and specific UC objectives identified during the first phase and developed in the second one.

This three-stage framework can be repeated, completely or partially, inside every experimentation cycle as much as needed in an agile and dynamic fashion.

3.1 The PDCA method

The Plan-Do-Check-Act (PDCA) is an iterative, four-step approach for continuously improving processes, products or services, as well as for resolving problems. This systematic method was developed in the 1950s by Dr. William Edwards Deming. For such, PDCA sometimes is referred to as the "Deming Cycle"[3].

Dr. Deming wanted to create a way of identifying what caused products to fail to meet customer's expectations. The PDCA method proposed by Dr. Deming was meant to help in developing realistic hypotheses about what needs to be changed, applying the changes and testing the refined product in a continuous feedback loop. It became an integral part of the Lean Management methodology, in which the PDCA is used as optimization tool.

During the four steps characterizing the method, the possible solution is tested, the results of the tests are assessed, and only the ones that prove to work are implemented.

The four steps are:

1. **Plan:** In this first step the problem (or the opportunity of improvement) is identified and analyzed. All the hypotheses are formulated during this step as well as the selection of which one has to be tested.
2. **Do:** This step is dedicated to performing all the tests concerning the potential solution. The solution is monitored from different perspectives and KPIs are defined to compare the current solution with the state of the art and with other possible solutions.
3. **Check:** The check step (also called "Study" step with resulting acronym PDSA) is dedicated to analyzing the results and to collecting the related KPIs, to measuring the effectiveness of the solution and to deciding if to implement the solution or not. Dr. Deming considered that "Check" applies more to the implementation of changes on a product, process or system, while "Study" is more generically oriented to prove hypothesis and studying the actual results comparing them to theories that want to be revised.

[3] https://balancedscorecard.org/bsc-basics/articles-videos/the-deming-cycle/

4. **Act:** This last step consists in implementing the solution if the Check step provides a positive outcome.

Figure 3 shows the PDCA method in its circular implementation.

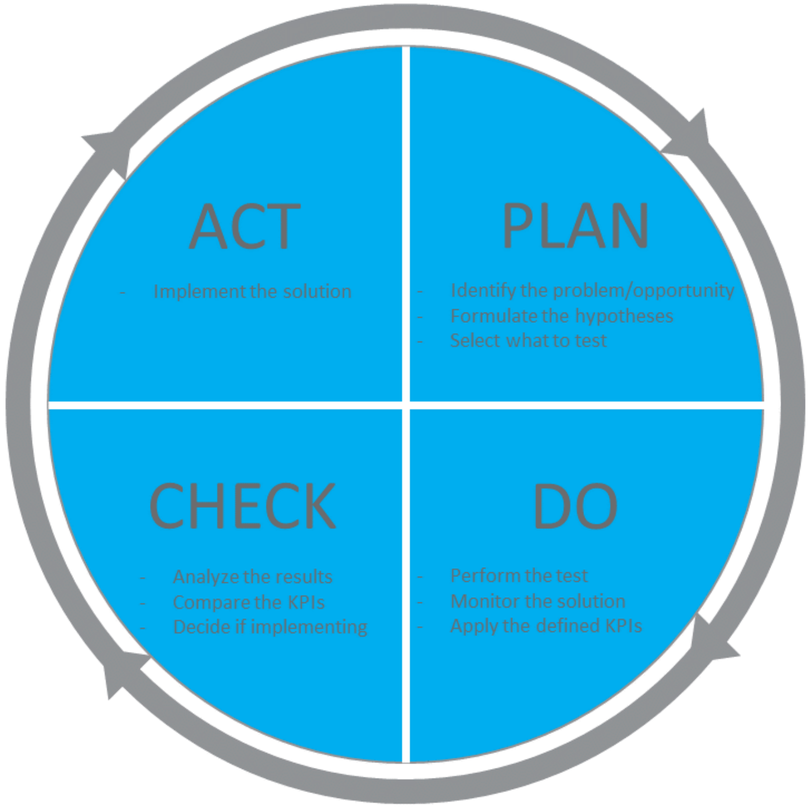

Figure 3: Schematic representation of the PDCA method.

There is no limit to the number of iterations of the Plan-Do-Check-Act as the Do-Check phases allow a continuous refining and repeating of the tests, and trialing potential solutions.

3.2 Adapting the PDCA to the 5G-SOLUTIONS cycles

The enforcement of the PDCA method to the 5G-SOLUTIONS UCs is not straightforward. Since each UC represents a real application of a new technology in a brand-new environment, some UCs may require preliminary tests to select the right technology and to implement suitable solutions that have never been designed and tested before. The final validation itself could be divided into separated executions, especially during the 1st cycle of trials when the involved UCs will perform the tests for the first time and several parameters will need to be adjusted, including the connectivity parameters playing a crucial role wherever no connectivity was active so far.

The PDCA is an iterative process that can be implemented both across the different stages described in Section 3, and inside each single phase to optimize the actions or the results. From a wider perspective, each of the 3 cycles planned in the 5G-SOLUTIONS project, starting respectively on M13, M21, and M29, and all characterized by 6 months duration, can be seen as 3 separated PDCA iterations or a sequence of PDCA iterations. Every iteration performs the planning (Plan), the execution (Do), the analysis of obtained results (Check), and the complete report analysis and improvement to be applied (Act), according to the PDCA iterative process that is repeated for the following cycle. At the end of every cycle, the report analysis performed in the 2 months between the current cycle and the following one, will highlight the issues faced and the missed opportunities. The next planning stage will take into consideration the faced challenges, redesigning the tests where necessary and preventing the risks.

From a closer perspective, the PDCA method can be used to optimize single tasks inside one of the stages. A clear example is the execution of the test trial: The Test Case can be planned according to the indication of the TMC team, executed; the result checked and evaluated discovering an improvement margin. A second iteration of the same test case considering the improvement possibilities detected will aim at improving the results as well.

4. Overview of the use cases with respect to the associated testbeds

The 5G-SOLUTIONS technical approach is based on a modular architecture in which various technological enablers are integrated together via open interfaces and APIs. These enablers will facilitate the measurement and visualization of 5G KPIs of the vertical use cases in near real-time whilst implemented in the field, as well as benchmarking and access from multiple locations, whilst promoting openness for the development of new innovative applications by 3rd party developers. The architecture features automatic resource scaling, by leveraging virtualization technologies and cloud automation scripts to elastically scale according to workload demand. This provides the necessary flexibility for the system to adapt to new interfaces, data sources, GDPR-compliant data processing, machine learning and representation requirements as may be required during the interfacing with the ICT-17 facilities.

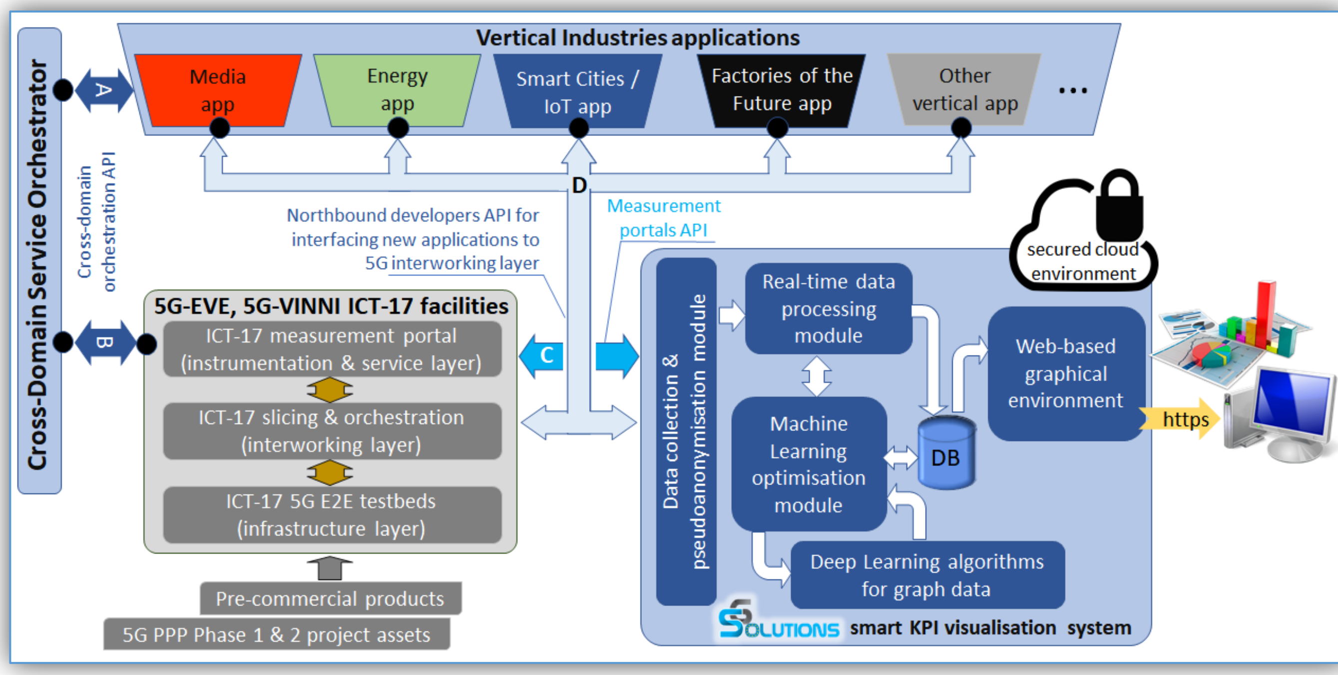

Figure 4: 5G-SOLUTIONS High-Level Architectural Concept

The high-level architectural concept of 5G-SOLUTIONS and its constituent elements are based on the aforementioned objectives and described below. With reference to Figure 4, the technological enablers to be implemented in 5G-SOLUTIONS and the interconnected 5G infrastructure (i.e. measurement portals, slicing, virtualization, 5G testbed orchestration and infrastructures from ICT-17 5G EVE Turin and 5G-VINNI Norway and Patra facilities) are indicated in blue and grey colors, respectively.

The facilities used during Cycle 1 trials per LL are presented in the Tables below.

Table 3: Cycle 1 Trials LL1 Facilities

UC	UC title	UC location	ICT-17 facility to connect to/ additional local RAN equipment
1.1	Time-critical process optimization inside digital factories	Brussels-Belgium, Ireland	One private 5G node will be installed within GLAN factory in Ireland and another within PBGS factory in Brussels, both provided by UOP, plus a new 5G RAN node by TNOR connected to 5G-VINNI Norway facility
1.2	Non-time-critical communication inside factories	Brussels-Belgium, Ireland	
1.3	Remotely controlling digital factories	Brussels-Belgium, Trondheim-Norway	
1.5	Rapid deployment, auto/re-configuration, testing of new robots	Trondheim-Norway	New 5G RAN node by TNOR connected to 5G-VINNI Norway facility

Table 4: Cycle 1 trials LL2 facilities

UC	UC title	UC location	ICT-17 facility to connect to / additional local RAN equipment
2.1	Industrial Demand Side Management	Turin-Italy	5G EVE, Italian Site in Turin
2.2	Electrical Vehicle (EV) Smart Charging	Turin-Italy	5G EVE, Italian Site in Turin Dedicated energy equipment will be used within the 5G EVE Italian Site in Turin to ensure proper communication operation and, for preliminary implementation before integration, in ENEL X's premises located in Rome
2.3	Electricity network frequency stability	Turin-Italy	5G EVE, Italian Site in Turin Dedicated energy equipment will be used with the 5G EVE Italian Site in Turin to ensure proper communication operation and, for preliminary implementation before integration, in ENEL X's premises located in Rome

Table 5: Cycle 1 trials LL3 facilities

UC	UC title	UC location	ICT-17 facility to connect to/ additional local RAN equipment
	Smart Cities		
3.1	Intelligent Street Lighting	Trondheim-Norway	New 5G RAN node by TNOR connected to 5G-VINNI Norway facility
3.2	Smart Parking		
3.4	Smart buildings / Smart campus	Dublin-Ireland	New 5G RAN node by UOP connected to 5G-VINNI Patras facility
	Smart Ports		
3.5	Smart port	Herøya-Norway	New 5G RAN node by TNOR connected to 5G-VINNI Norway facility

Table 6: Cycle 1 trials LL4 facilities

UC	UC title	UC location	ICT-17 facility to connect to / additional local RAN equipment
4.1	Ultra High-Fidelity Media	Patra-Greece	5G-VINNI Patras facility
4.4	User & Machine Generated Content	Patra-Greece	5G-VINNI Patras facility
4.6	Cooperative Media Production	Patra-Greece	5G-VINNI Patras facility

5. Cycle 1 trials deployment planning

In this section exists an analysis of each UC participating in Cycle 1 trials in terms of architecture, information flow, planning and test cases. All four LLs are adequately represented in Cycle 1.

5.1 LL1: Factories of the Future (FoF)

5.1.1 UC1.1: Time-critical process optimisation inside digital factories

5.1.1.1 *UC test objective and design*

UC1.1 “Time-critical process optimization inside digital factories” will explore the possibility of implementing an in-line product monitoring system and process analytic technologies for replacing the current off-line product quality assessment approach.

Quality assurance and quality control are two key aspects for the manufacturing industry with a direct impact on the industry’s business, increasing the loyalty of the customer, building the brand and maintaining the brand’s reputation, creating the perception that the product has a better value for money ratio than competitors, all these aspects leading to a profitable business.

The current approach of many manufacturing and consumer good production factories to ensuring that the quality of their products consists of adopting a close feedback control loop mechanism to control process parameters that impact the overall quality of it.

Such an approach is typically used for off-line quality assessment, where the product inspection happens separately from the production line. Off-line inspection requires a product to be removed from the production line to be inspected and evaluated. A statistically significant number of products to be inspected (samples) allow the Quality Assurance system to gather statistics about the overall production efficiency and the overall product quality, to estimate, out of these numbers, the impact on the business. The product defect can be identified, but the late defect identification does not allow providing timely feedback to the process supervision. In case of massive production affected by several defects, the statistically significant number of samples can be high, increasing the scrap quantity.

In contrast, in-line quality assessment mechanisms integrate techniques to inspect each single product at the end or during the different production phases. Being an in-line and automated procedure, ensures that every product (and/or every part composing it) is inspected. This requires less time than the off-line inspection methods. Data from the inspection scan can be used as feedback to the production process in real-time reducing waste and increasing the efficiency of the overall production process. Moreover, given that each single product is inspected, the data analysis to evaluate efficiency and business impact can be done without resorting to statistical methods based on observation of a limited number of samples.

The production line selected has been designed without considering the possibility of implementing an artificial vision, in-line product monitoring, and this requires some preliminary tests to be performed before the actual implementation in the factory environment.

The first cycle of tests represents a challenging opportunity to put in place the architecture designed and test the hardware that is completely new to the market and has never been tested for this type of solutions. This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.1.1.2 *UC architecture and components*

The final implementation foresees various components, depicted in Figure 5.

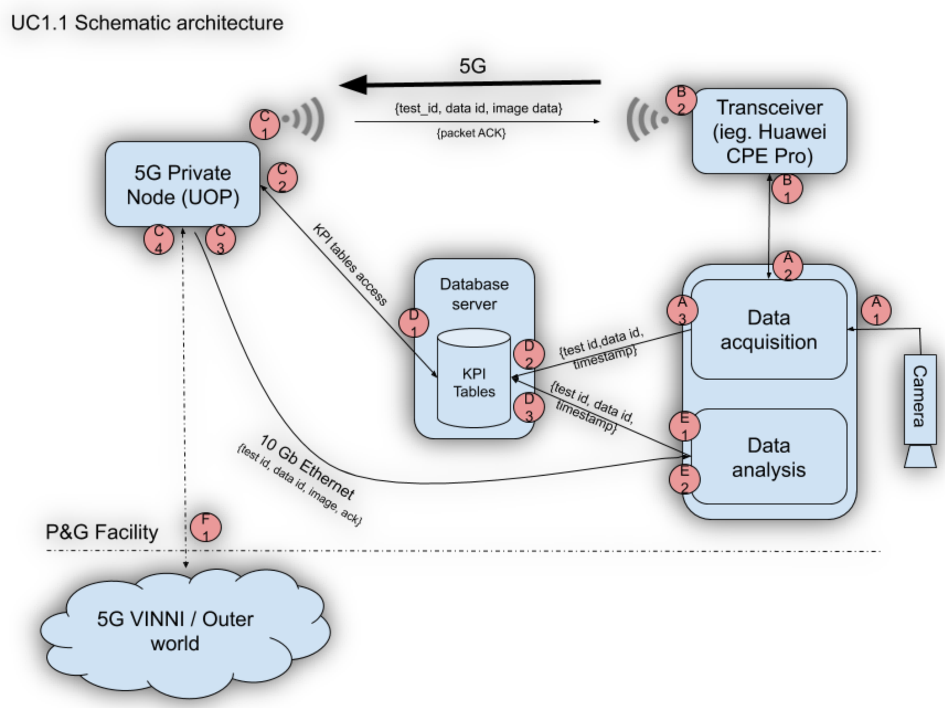

Figure 5: UC1.1 schematic architecture representing the main components

The *Camera* component is the sensor grabbing images of the product while it is moving on the underlying conveyor belt. The camera is a high frame-rate camera equipped with 4 CMOS sensors: 3 for RGB and a fourth one working in the infrared spectrum. The *Data acquisition* module is responsible of controlling the operation of the camera (e.g., maintaining the camera synchronized) and acquiring the raw images. After an image is acquired, it needs to be fragmented and packetized to be offloaded to the 5G-transceiver.

The 5G *Transceiver* is a crucial component, and the selection of the most suitable one on the market is still under evaluation. The market currently does not offer a big choice of this type of transceiver but the trend and the announcements from the main chipset integrators lets us believe that new a 5G development kit will be released soon. The 5G-transceiver has the duty of wirelessly offloading the generated data to the 5G private node. This architectural component is supposed to be a stand-alone device that can be remotely configured, monitored, and controlled. This also represents the one point of access from an outer network and for inbound/outbound traffic. For data confidentiality reason, the access to the 5G facility network has been limited, at least for Cycle 1.

The last component of the data analysis chain is the *Data analysis* module. Such a module is responsible for receiving the image, analysing it, detecting if there is a defect in the product and, in the positive case, provide a trigger to a rejection system (not in place for cycle 1) to remove the defective product from the production line. The Data analysis module integrates a machine learning algorithm for not only the detection of a defect, but also the automatic identification and classification of the defect. Having statistics about the type of defects and their relative patterns is important for future process optimization. The Data acquisition and the Data analysis modules can be collocated in the same hardware case (as depicted in Figure 5) or they can be hosted in two different hardware components. In this document the one module including Data acquisition and Data analysis is called Data Processing module.

The set-up depicted in Figure 5 is a simplified version of the quality control system that ideally would be in place at factory scale. This simplified version has the aim of providing proof of concept validation either for the artificial vision system and the wireless data offloading architecture. In a factory scale deployment, various production lines would be involved, each of them equipped with several cameras to cover the whole production process. All the cameras would wirelessly offload the frames recorded to a single data analysis unit that won't necessary be located in the same area where the production happens, but it could be deployed in a separated control room or even in a secured cloud computing service.

A simplified flow-diagram showing the interaction between the different components is depicted in Figure 6.

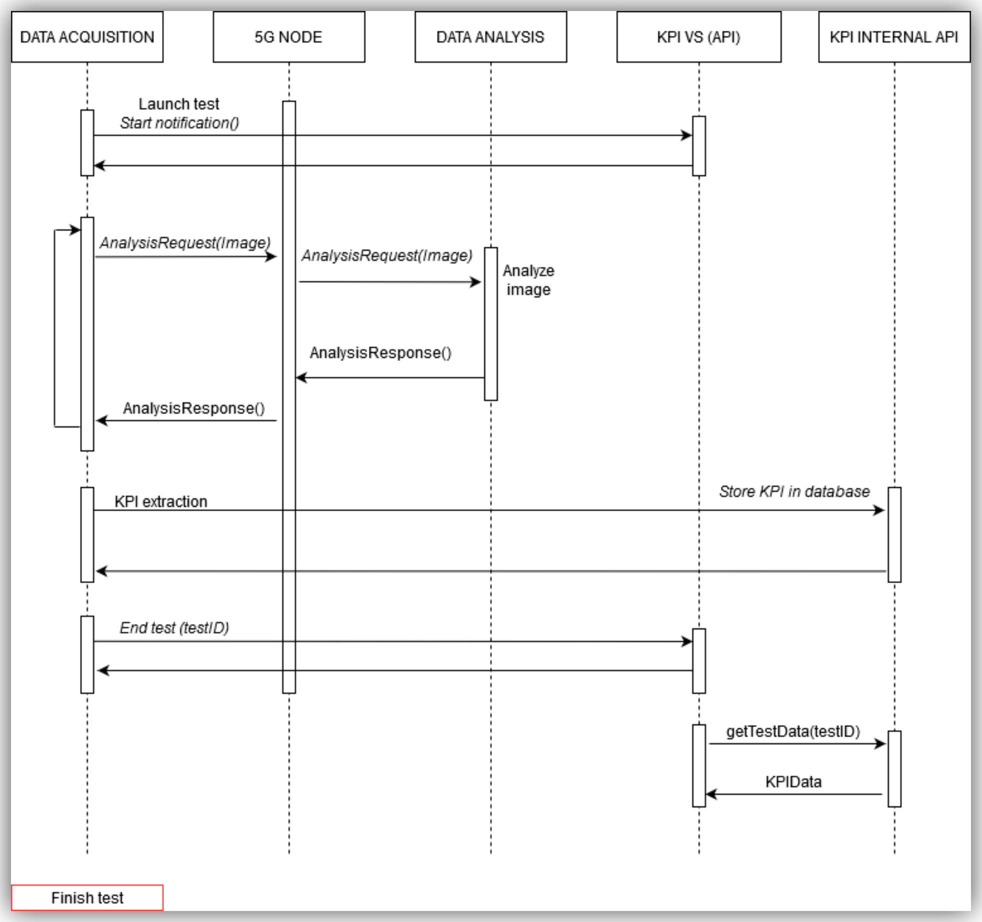

Figure 6: Simplified sequence diagram of a test

Every test case is identified by a unique ID, and the KPI visualization system is informed that a test is due to start through a specific REST API, as well as a notification of a test finalization will be sent. During the test execution, different KPIs are measured at application level.

All statistics and metrics gathered in the different points of the architecture depicted in Figure 5 will be stored in a local database. The same database will be shared with the KPI Visualization System through a dedicated API whose purpose is to provide access to the stored data. Once a test session starts, the KPI Visualization System in informed by sending a start_test() request. In the same way the KPI Visualization System is aware of the finalization of the test through a stop_test() request. This is necessary to let the KPI Visualization System know when new data can be available on the database, and if concurrent tests are running in parallel. The parallel running of more tests is not in the scope of Cycle 1, but it is a possibility that can be considered in future iterations. The API provides two endpoints:

1) "/Tests" returns a list of all available tests.

2) "/Test/id" returns all the information related to a single test, with the raw data and KPI that the system has collected during the test.

5.1.1.3 *Test Planning*

The deployment of UC1.1 presumes the readiness of the various software and hardware blocks composing the architecture. Before implementing the final deployment into the factory facility, a series of actions have to be taken to prepare the architecture, building a baseline towards comparing the results achieved, and testing the single components.

Even though the planning of the tasks follows a waterfall approach, given the strong interaction and the interdependencies between the different actions, each one of the tasks will be executed following an agile fashion. This means that every entry of the work breakdown structure (the high-level list of tasks) will be expanded in a process backlog (listing the actions and tests to be performed during the execution of the task). In parallel, the process backlog exposes the dependencies with other tasks and such, the need of repeating the single action to produce an improvement in the result, exploiting the PDCA approach described in Section 3.

The general plan for UC1.1 is depicted in Figure 7.

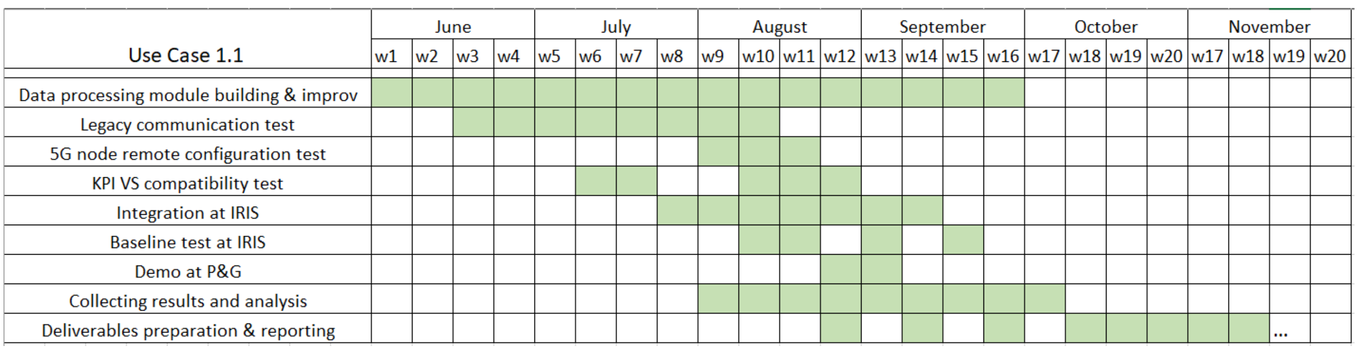

Figure 7: Planned tasks execution for UC1.1

5.1.1.4 *Test scenarios definition*

Following, there exists a description of the high-level scenarios and test cases.

Data Processing module building and improvement

The first task to be executed is concerned with the design and development (and the future improvement) of the Data processing module (including the Data Acquisition and Data Analysis modules). This module and the operations provided by it are strictly dependent on the data (type, format, dimensions, etc.) so its development and improvement will progress throughout the majority of Cycle 1, providing continuous increments ideally every month. This work (almost entirely related to software development) will be carried out by the development team in IRIS.

Legacy communication test

The legacy communication test aims to perform a series of tests using a more common technology such as WiFi 802.11ac. The purpose is to evaluate the performance of this legacy wireless communication system replicating as much as possible the conditions in which the communication with the 5G node will happen. These tests will generate a performance baseline, other than helping to overcome technical difficulties that can be encountered later (for instance, the correct integration of the Data Acquisition module with the transceiver). Initially the tests will be conducted using traffic generation and traffic monitoring tools such as netperf[4],

[4] https://hewlettpackard.github.io/netperf/

iperf3[5], tcpdump[6], etc., and once the image processing will be mature enough, the tests will be performed using real images of the product captured from the camera. The entire set of tests will be executed in IRIS' laboratories.

5G node remote configuration

The set-up and configuration of the 5G private node represents a crucial point of the final installation in the factory facility. The P&G facility presents numerous security policies aimed at impeding malicious access from external networks. The 5G node provider, UOP in this case, needs to remotely access the 5G node once it is installed into the P&G facility. The remote accessibility of the 5G private node is also important for retrieving the measured parameters from the database. In order to avoid as much as possible any inconvenience at the time of the deployment in the factory, remote connection and set-up tests will be performed. Once P&G and UOP have agreed on the connection modality, the same conditions will be recreated in IRIS premises, where the 5G node will be shipped, so that UOP will be able to perform the necessary remote connectivity tests.

KPI Visualization System compatibility

This set of actions has the double objective of:

1. Prove (and in case adapt) the format compatibility of the data stored in the local database and the data expected by the KPI Visualization System to perform the processing.
2. Validate that the data stored in the local database are accessible through the 5G private node and can be collected.

The execution of the tests will be similar asin the 5G node remote configuration case: IRIS will reproduce as much as possible the network conditions that will be encountered in P&G, with the difference that AppART (responsible for the KPI Visualizations System) will be involved in collaboration with UOP.

Integration at IRIS

Before moving to the factory plant, IRIS will use its laboratories to replicate the architecture as it will be deployed in P&G. This will give the chance to validate the correct integration between all the system components and their interoperation. During this phase, there will be the possibility of performing baseline tests of the whole architecture using the legacy technology and building solid baselines towards comparing the results. Ideally, it would be beneficial to perform the same set of measurements that will be done in the demo, also using the 5G node and instantiating the 5G connection.

Demo at P&G

The final demo at P&G will crystalize the work done in cycle 1, bringing all the developed architecture to the production plant. The camera will be installed on the production line, and the rest of the components will be placed inside the factory floor. If possible, not only the tests using the 5G connection will be done, but the legacy connectivity tests will be executed as well. The execution of the legacy connectivity tests and the comparison with the baseline tests will help to identify physical differences that affect the results (the presence of scattering points, other wireless communication that interfere, etc.) and that can be useful for future improvements.

Collecting results

All across the execution of cycle 1, the actions performed and the results achieved will be reported and documented. However, the analysis of the results is an important phase that will be executed in parallel to the experiments to investigate the possibility of improving the solutions that are in place. The results and the analysis of the collected data will be also reported in the end of cycle deliverables.

[5] https://iperf.fr/
[6] https://www.tcpdump.org/

5.1.1.5 *Planned KPIs for testing*

A series of technical KPIs will be measured at application level in cycle 1. At the time of writing, not all of the hardware is available. Therefore, before having the hardware in place, it is difficult to know exactly what it will be possible to measure. However, a list of specific desired KPIs has been put in place:

- Upload/Download average throughput [Mbps]
- Upload/Download peak throughput [Mbps]
- RSSI [dBm]
- Packet Loss [%]
- Latency Average [ms]
- Latency Standard Deviation [ms]
- Jitter [ms]
- Inspection time [ms]
- Overall reliability [%]
- False positive rate [%]
- Successful detection rate [%]

It is improbable that in cycle 1 all of these KPIs will be measured and given the experimental nature of Cycle 1 for this UC, other KPIs and metrics can be added during the execution. Considering the hardware available at this stage, a series of KPIs and parameters of interest have been set with the objective of at least measuring those in cycle 1 and preserving the results for comparison with future iterations. This set of KPIs is related to the application level of the deployed stack, which is supposed to be the same across the different tests and the different cycles. In particular, the application level KPIs selected can be measured and stored as an auxiliary service of the Remote procedure Call (RPC) protocol used.

The RPC protocol that has been decided to be used belongs to the gRPC framework[7] that offers a bidirectional streaming and flow control. gRPC exposes some metrics and parameters that are useful to benchmark the application level. From these metrics it is possible to instantly extract the throughput at application level, the number of requests per second, the ratio between the successful/failed requests and the total number of requests to validate the reliability, and it is possible to extract different statistics about the latency. Particularly useful for this UC is the possibility of generating a latency histogram that can help validating the overall performance of the system considering a possible future implementation of a timestamp-based rejection mechanism.

Specifically, for cycle 1, the KPIs that have been planned to be measured are the following:

- Number of gRPC requests performed in the experiment. This parameter is directly related to the number of images acquired.
- Total duration of the experiment.
- The average latency measured between two gRPC services.
- The minimum latency measured between two gRPC services.
- The maximum latency measured between two gRPC services.
- The number of gRPC requested per second. This parameter is directly related to the application-level throughput.
- Latency distribution data to build a histogram.

A gRPC instance will run in the Data Acquisition node and in the Data Analysis node, providing an overall characterization of the experiment results through the listed parameters. It is currently under evaluation the possibility of having a gRPC instance running in the 5G private node to have a better data granularity by segmenting the architecture at application level.

[7] : https://grpc.io/

5.1.1.6 *Test cases*

To measure the KPIs selected for cycle 1, and to prepare the architecture for its deployment into the factory floor, different test scenarios have been designed, as depicted in the tables below:

Table 7: UC1.1 test scenarios

Scenario ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC1.1-SC1	Baseline creation scenario	U-SC	Scenario without production process to create a baseline	Generate a set of parameters used for technology comparison
UC1.1-SC2	Lab demo scenario	U-SC	Final scenario reproduced in lab	Generate a set of parameters used for context comparison
UC1.1-SC3	Factory demo scenario	U-SC	Final in-factory scenario	Measure and validate metrics and KPIs

Table 8: UC1.1 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC1.1-TA1	IRIS premises - data modules test	unit, component	Preliminary test of the Data acquisition and Data analysis modules	Test the correct working of the Data acquisition/analysis module, the latency and the achievable throughput using direct connection or localized architecture
UC1.1-TA2	IRIS premises - legacy connection test (baseline)	partial integration, component	baseline tests using legacy technology such as 802.11ac	Measure the latency and throughput of the legacy technology to create a comparison baseline. Some preliminary test could be performed only on connectivity side measuring parameters on specific interfaces generating synthetic data
UC1.1-TA3	IRIS premises - 5G node remote configuration	unit	Configuration and measurement test of the 5G private node from UOP installed at IRIS using the same connectivity method that will be used at P&G.	Test the possibility for UOP to access the node remotely, configuring it and gathering radio statistics

Table 9: UC1.1 Test Cases Matrix

	TC01	TC02	TC03	TC04	TC05	TC06	TC07
Test Areas	UC1.1-TA1	UC1.1-TA2	UC1.1-TA3	UC1.1-TA4	UC1.1-TA5	UC1.1-TA6	UC1.1-TA7
Target Vertical KPIs - Primary & Secondary							
Uplink throughput		X			X	X	X

Inspection and elaboration latency	X	X			X	X	X
Indoor communication range		X				X	X
Reliability					X	X	X
False negative rate							X
Scenario ID							
UC1.1-SC1		X			X	X	
UC1.1-SC2					X	X	
UC1.1-SC3							X

5.1.2 UC1.2: Non-time-critical communication inside factories

5.1.2.1 *UC test objective & design*

UC1.2 will leverage the 5G technology as enabler for multi IIoT sensor's data gathering. The environment in which this UC will be developed is a large-scale dairy production facility. Currently the vast majority of the data reporting information about the plant is gathered from Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCSs) that control the production plant. The information collected by these systems is concentrated in a Manufacturing Execution System (MES) which consolidates and contextualizes the data providing a data-driven status of the production plant. The output is presented on a graphical user interface accessible through a browser, providing a model for the operational status and historic data series for problem investigation.

Over the years, this solution proved to suffer some gaps. One of the key gaps of the current MES solution is the lack of data to conduct an exhaustive problem investigation or to apply coherent initiatives for optimizing the processes. Given that this data is not supposed to participate in the actual control of the production, the acquisition of this data can become prohibitive under the implementation perspective in the current solution. Also, the integration of extra data sources with the running solution can be difficult and timely and/or economically not profitable.

The objective of this UC is to provide a sufficient coverage, endpoint isolation, and information delivery in a controlled and fully managed environment. The wireless nature of the connection will ensure the collection of data from sensors placed in locations that cannot be reached by a cabled connection (for physical or economic reasons), enriching the dataset with environmental data that can be merged with the existing plant model, facilitating the problem investigation and analysis, paving the way for predictive maintenance and downtime reduction. The coverage of certain areas of the plant will allow the easy re-deployment of sensors and the installation on moving equipment. Lastly, but not less important, the data granularity can be enhanced, changing not only the provisioning methodology (interval-based, polling-based, availability-based) but the rate within which the data is gathered, from multiples of seconds to fractions of seconds.

The complexity of the environment where the UC will be developed leads us to organize the UC execution in two main phases to limit the risks related to the experimentation in a running factory environment. The first phase complies with a series of actions (Test Areas) designed to create a baseline, to prepare, and to test the actual UC in a more accessible and less constrained environment than the one that will be met in the factory. The idea is to have experienced the possible issues (or at least the more common ones) in the safe environment where it is more comfortable and easier to solve any issue that might occur, and get to the second phase with a ready-to-deploy system. The second phase consists in repeating the key actions in the actual factory environment, specifically the final test areas. This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.1.2.2 *UC architecture and components*

The reference architecture to which the final test area is referring to is depicted in Figure 8.

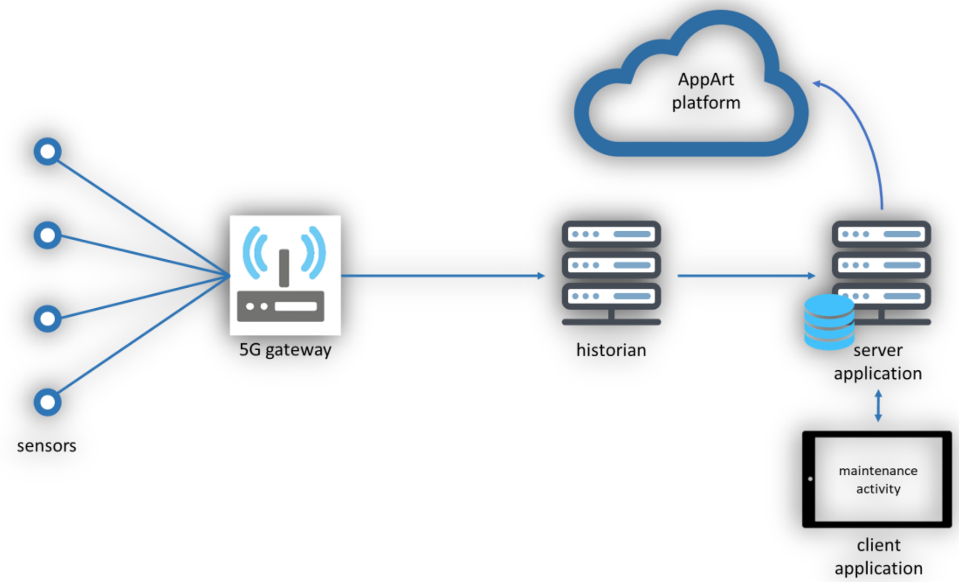

Figure 8: Schematic representation of the UC1.2 architecture

Data from sensors are collected to a 5G gateway[8] by means of LoRa protocol. LoRa is a low-power wide-area network protocol that aims to deploy a sensor network used to bring data to the gateway. The gateway, through 5G node connection, stores data into the historian database[9] with an OPC/OPC-UA interface.

The server application runs a SQL Server database for aggregated data. In fact the maintenance application does not need to contain all trends data, but, based on those trends, it needs to open new activity maintenance. The component in charge of creating the aggregated data is a Windows Service called Integration Service. The Integration Service runs periodically and can also trigger the creation of other attributes related to the trends or the time (e.g., every month it can open a new maintenance activity on a certain valve and assign to that some tasks). Moreover, the Integration Service sends KPIs to the KPI Visualization system (ref. WP3).

Data in the SQL database are shown by means of a client application. The client is a web application usable with a web browser like Chrome or Firefox. Data are requested by REST API to a proper web service.

5.1.2.3 *Test Planning*

UC1.2 aims to be deployed inside a running large-scale dairy production facility. This implies some risks, both for the running production process that could suffer downtime or interruption, and for the successful implementation of the UC. For this reason, it has been decided to divide the implementation in two main phases. The first phase is dedicated to the preparation of the UC, performing preliminary tests, creating a baseline towards which the results will be compared, and implementing all the actions necessary to adapt the architecture to be deployed in the factory environment in the most seamless way possible. The second phase consists in the deployment in the factory environment and the actual test running.

[8] https://www.advantech.com/products/1-2kwkn0/active-stylus/mod_e1559c96-c6f8-428f-a95e-fdf7c274afdf Advantech gateway

[9] https://www.aspentech.com/en/products/msc/aspen-infoplus21 AspenTech IP.21

The first phase consists in 5 Test Areas that will be developed in the ORBIS premises, while the second phase foresees 2 main Test Areas taking place in the Glanbia factory facility. The planned activities are depicted in Figure 9.

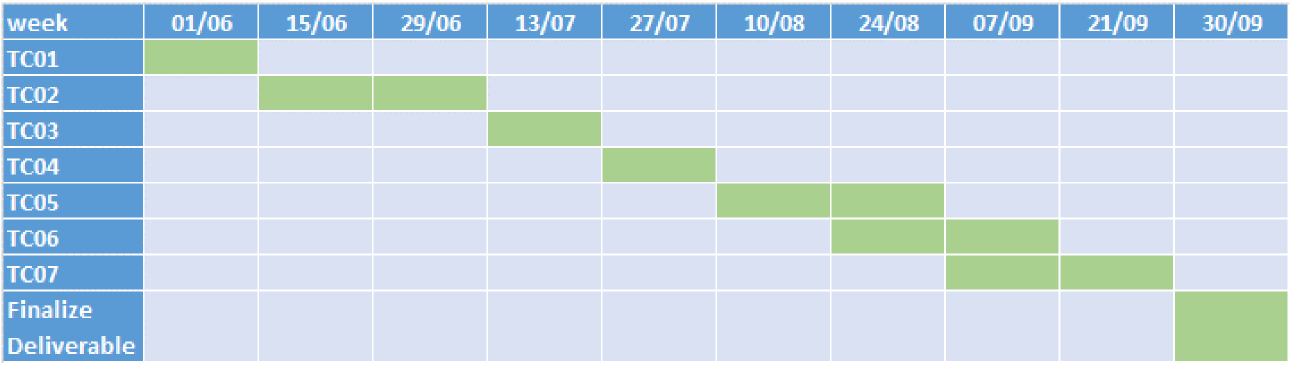

Figure 9: Planned actions for cycle1

5.1.2.4 *Test scenarios definition*

<u>MES integration tests</u>

The 5G test cases will be integrated with the existing Glanbia IT/OT infrastructure in the Glanbia Living Lab, as described in UC 1.2. It is subdivided to the use case 1.2a and use case 1.2b.In UC1.2a, time series plant data gathered from wireless sensors in the 5G operating area will be time synchronised with data arriving from the plant PLC equipment and stored in the existing MES (manufacturing Execution System) Historian. KPIs that measure the end-to-end data transfer time from sensor to historian are of interest.

In UC1.2b, a 5G enabled mobile device operating in the 5G coverage zone will run an application that integrates with the Glanbia ERP (Enterprise Resource Planning) system, specifically the SAP Maintenance module. The KPIs of interest in the UC will measure the value of improved turnaround times on management data availability and completeness as it relates to the completion of maintenance work orders.

The Maintenance application and MES have the same database structure and hence they implement the same web service. The two systems may then share the same DBMS and web service and be integrated with each other. However, at least in the first stage, they will be kept separate since the utility of the information from the two systems is different and the best data management strategy for the company is to keep a separation of concerns. Nevertheless, the MES, apart for the core functionalities, can be seen as a collection of tools (Track&Trace, Reporting, etc.) where the Maintenance application can fit. As a result, the maintenance application will be a tile in the MES system, a link that redirects the MES application to the Maintenance application in one click. Moreover, the MES can display reports integrating data from the Maintenance application database for KPIs analysis or management overview. For the reasons explained, the integration tests will be reduced to a check on the link tile.

<u>Legacy connection tests</u>

As all the UCs in LL1, UC1.2 never implemented this type of solutions. For this reason, the creation of a baseline is necessary. The baseline will serve not only from a technical perspective, as a benchmark towards which we compare the final results, but also as an initial metric to validate the feasibility of the implementation under a business-oriented perspective providing the UC owner with a reference technology that can be taken as reference for a cost/benefit analysis.

By means of a 5G device (new generation smartphone or tablet) we will connect to the 5G node and record KPIs through the specific mobile applications shown at points a) and b).

a) Network Cell Info

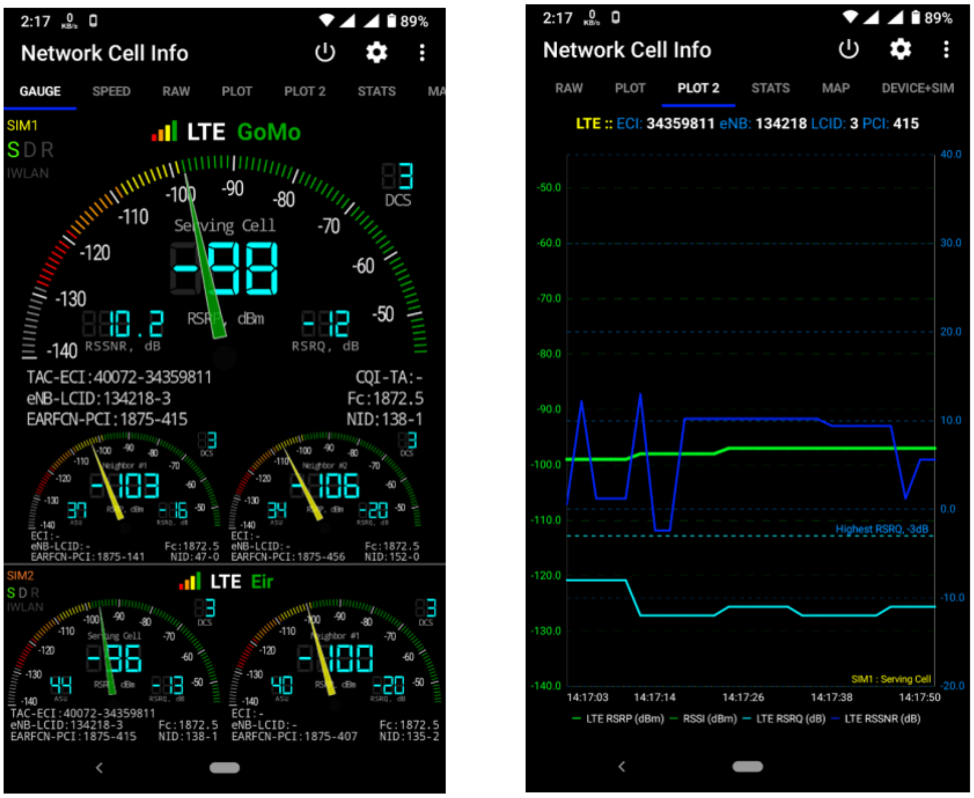

Figure 10: Network Cell Info App Screenshots

b) Hurricane Electric Network Tools

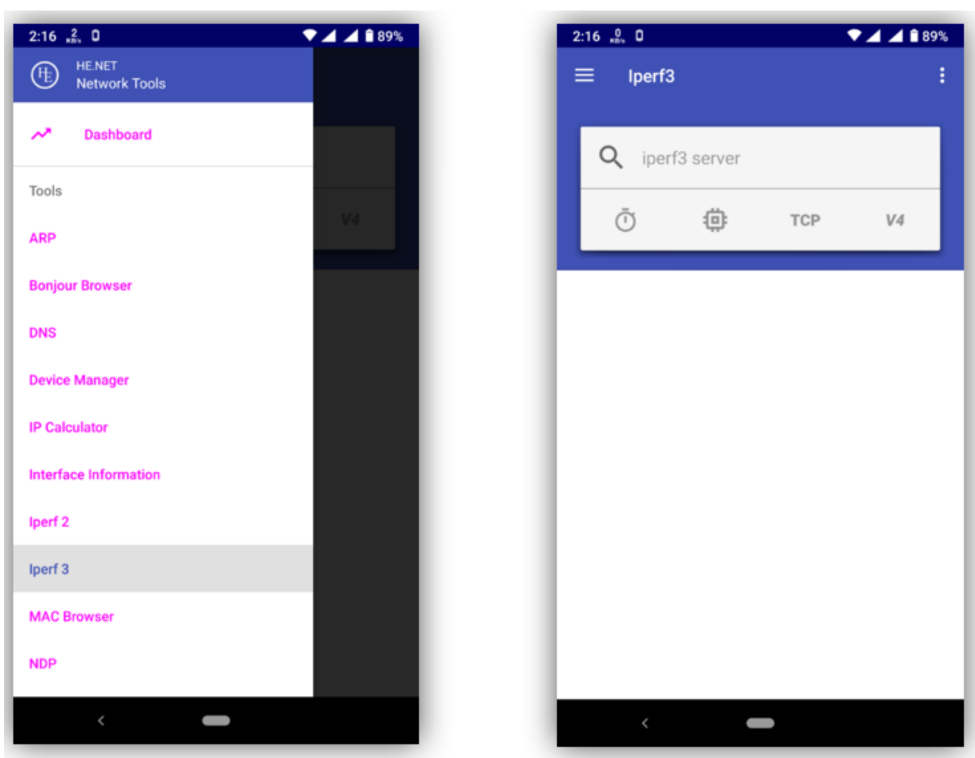

Figure 11: Hurricane Electric Network Tools screenshot

5G private node remote configuration

The configuration of the 5G private node has to be done remotely by the technology provider partner (UoP in this case). The factory environment is a protected environment and any external network access is forbidden for security and confidentiality reasons. The 5G private node must however be deployed inside the factory environment and needs to be remotely accessed by the technology provider to set it up and for maintenance actions. This test aims to replicate the factory network infrastructure to guarantee the access to the node without compromising the security of the networking infrastructure itself.

Orbis replicates the plant infrastructure on premise in a small demo lab environment, simulating de facto the Glanbia site in term of data flow and tools. The demo lab will be also very useful for development and alpha/beta tests.

Full system connection test

Although each connection and interface of the system between two components is tested autonomously (integration test), a full system connection test will be performed (Canary test). This is done demonstrating that the UI displays sensors data or a result of an elaboration of those (e.g., a new maintenance activity).

Preparation for the in-factory deployment

The demo lab will involve the entire software chain needed for the project. Moving from the lab to in-factory environment will require reinstalling all the software on the server on-site. For some off-the-shelf software, the purchase of a commercial license is necessary, whilst for all the Orbis software it is a matter of installing libraries and configuring all the services accordingly. From the hardware perspective, we need the 5G node to be deployed and ready to use, the IoT gateway located and configured on-site and monitored assets connected.

Baseline connection tests

The tests on the demo lab give us a big advantage testing the connection between most of the components involved in the architecture, but we cannot really verify the effective performance of the 5G network and of the overall system until we start testing the architecture on site. In this test area, we can focus on the real 5G performance KPIs and the effective advantages the 5G brings over other technologies. Beyond the deployment and starting of the system, using a 5G mobile device, we can benchmark the performance by means of the smart applications referred above: Network Cell Info and Hurricane Electric Network Tools.

Final demo

The final demo involves all components of the application. It is an important TC since we can test the responsiveness of the web API at full load. Since the UI is web-based we can use the development tool the browser provides to track HTTP calls (e.g., Figure 12).

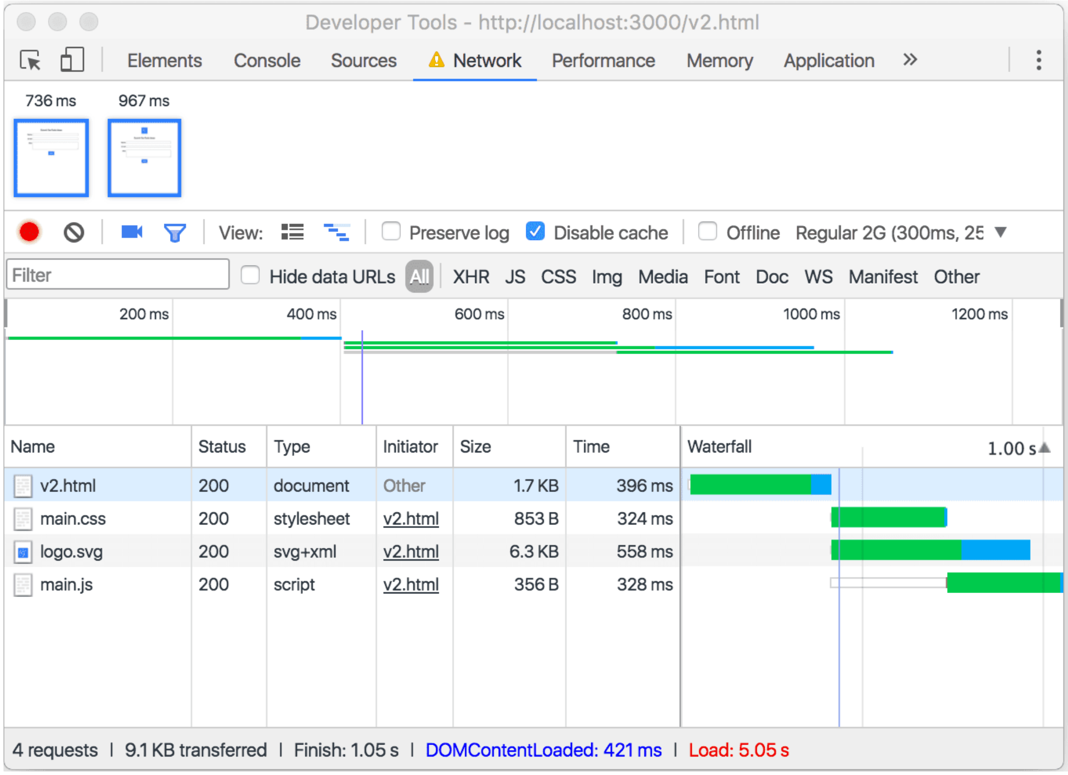

Figure 12: Chrome browser development tool screenshot

At this stage, the KPIs gathered so far are verified again and the results are compared with on-premises KPIs and the performance recorded on WiFi.

Finally, we can test the interface with the ERP returning the maintenance records. This final test can be run only on site due to network access restriction from another server outside the Glanbia internal network.

5.1.2.5 *Planned KPIs for testing*

The first cycle of experiment is the first challenging test bench for this UC. Some KPIs have been selected, but it is likely that new KPIs and metrics will be exposed in the subsequent cycles as a result of this first iteration.

Technical KPI

- RSRP [dBm]
- RSSI [dBm]
- RSRQ [dB]
- RSSNR [dB]
- Packet Loss [%]
- Latency Average [ms]
- Latency Standard Deviation [ms]
- Jitter [ms]
- Throughput [Mbps]

5.1.2.6 *Test cases*

The UC1.2 test cases are:

Table 10: UC1.2 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC1.2-SC1	Baseline creation scenario	U-SC	Scenario without production process to create a baseline	Generate a set of parameters used for technology comparison
UC1.2-SC2	ORBIS demo scenario	U-SC	Final scenario reproduced in lab	Generate a set of parameters used for context comparison
UC1.2-SC3	Factory demo scenario	U-SC	Final in-factory scenario	Measure and validate metrics and KPIs

Table 11: UC1.2 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC1.2-TA1	ORBIS premises - MES integration test	unit, component	Installing and preliminary test of the software components for the MES integration	Decide and test which sensor's measurement will be integrated to the existing MES solution
UC1.2-TA2	ORBIS premises - legacy connection test (baseline)	partial integration, component	Baseline tests using legacy technology such as 802.11ac	Ensure the latency and throughput of the legacy technology to create a comparison baseline. Some preliminary test could be performed only on connectivity side, measuring parameters on specific interfaces generating synthetic data
UC1.2-TA3	ORBIS premises - 5G node remote configuration	unit	5G private node from UOP installed at IRIS using the same connectivity method that will be used at P&G. Configuration and measurement test	Test the possibility for UOP to access the node remotely, configuring it and gathering radio statistics
UC1.2-TA4	ORBIS connection tests	unit component	Connection tests between the IoT gateway and Kepware data collector	Test the possibility of initiating/terminating a test, polling/pushing KPIs, AppART able to retrieve from database
UC1.2-TA5	ORBIS premises - integration	integration	reproduce partially the GLAN scenario and perform a series of tests	In premise scenario reproducing the in-factory one. The aim is to perform the tests before shipping the material to GLAN
UC1.2-TA6	GLAN premises - baseline test	integration, e2e	Integration at the factory premises, baseline run	In-factory scenario reproducing UC1.2_TA_2 tests
UC1.2-TA7	GLAN premises - demo	integration, e2e	Integration at the factory premises, demo run	In-factory scenario reproducing UC1.2_TA_5 tests

Table 12: UC1.2 TCs Matrix

	TC01	TC02	TC03	TC04	TC05	TC06	TC07
Test Areas	UC1.2-TA1	UC1.2-TA2	UC1.2-TA3	UC1.2-TA4	UC1.2-TA5	UC1.2-TA6	UC1.2-TA7
Target Vertical KPIs - Primary & Secondary							
Mobile sensor response to poll					X	X	
Cim/IO data transfer to historian						X	
TCP session metrics	X	X	X		X	X	
Throughput			X		X	X	
User experience							X
Time to access and render maintenance SOP URL							X
Security				X	X		X
In/Outdoor communication range	X	X			X	X	
Scenario ID							
UC1.2-SC1		X			X	X	
UC1.2-SC2					X		
UC1.2-SC3						X	X

5.1.3 UC1.3: Remotely controlling digital factories

5.1.3.1 *UC test objective & design*

While in both UC1.1 and UC1.2, local on-site communication is assumed within the plant, in the case of UC1.3, the public wireless access network also plays a role in the end-to-end communication between remote workers and the facilities within a factory. The simplest setup of this use case involves remote control applications running on tablets or smart phones for example. Latency is particularly important for real-time, remote motion control of local robots. Edge computing within the network is required for fulfilling the low latency requirements.

In view of the trend of new AR devices, it is likely that new remote services may arise that facilitate the creation of virtual back-office teams. Such remote teams may use the data coming from smart devices for preventive analytics and easy access to work instructions, whereby, for example they would be able to view the camera or iPad/Google Glass of a local worker. In this part of the use case, there is a less stringent need for low-latency. Interaction times up to seconds are acceptable for remote servicing machines. However, high availability is key for allowing (emergency) maintenance actions to occur immediately. Bandwidth is important for video-controlled maintenance, with real-time augmented content mixed into the video signal.

The following Use Case Scenarios (UC-S) will be studied in this UC:

- UC 1.3_UC-S_1: Remote control of AGV (Direct control and indirect, planned operation)
    - UC-S 1.3_1.1: Operators in local control-room
    - UC-S 1.3_1.2: Operators at remote location, i.e., at least 500km (Distance Trondheim - Yara Porsgrunn)
- UC 1.3_UC-S_2: Remote control of stationary robots (Direct control and indirect, planned operation).

    - UC-S 1.3_2.1 Operators in local control-room
    - UC-S 1.3_2.2 Operators at remote location, i.e., at least 500km (Distance Trondheim - Yara Porsgrunn)
- UC 1.3_UC-S_3 Semi-local operation / control with use of AR-information added to operators UI[10]
    - UC-S 1.3_3.1 AR-information processed and added at local site, edge computing
    - UC-S 1.3_3.2 AR-information processed and added at remote location, i.e., at least 500km (Distance Trondheim - Oslo)

The only relevant security threat that can realistically be looked into in this UC, is the possibility of some form of DoS attack that can affect the ability to uphold the real-time requirements in general. We assume two possibilities, that the local 5G network is temporarily jammed, or that the overall 5G infrastructure is compromised. Neither of these scenarios can be tested in our case due to the magnitude of the supposed threat. The possibility of detection of such a situation can perhaps be studied though, and if ensured, it allows for fail-safe operation of the remote control.

Yara is an end user of the 5G system. This means that the tests performed are linked towards the business need with focus on the functionality of the 5G network. Key issues for Yara are real time capability, availability and high cyber security capability (it needs to be secure, not creating a back door into Yara's network). Yara also wants to understand the limitation of the 5G system to see future potential use of the network according the need to utilities the possibilities of Industry 4.0.

This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.1.3.2 *UC test design*

The experiments will be performed at MTP NTNU, MTP NTNU together with Yara, and at Yara. At MTP NTNU there are several industrial scales, physically and logically interconnected robotics laboratories being completed as of the summer 2020. These are part of the NFR (Norwegian Research Council) supported initiative Manulab (See e.g., https://www.ntnu.edu/ivb/manulab). These laboratories at MTP at Gløshaugen in Trondheim consist of several interconnected parts, a general robotics laboratory for welding, one for use with robotized direct construction of casting-forms, stations for automated shaping of metallic pipes and a section with several smaller robots and operator stations to study Industry 4.0 concepts, this especially in conjunction with the AGV lab.

MTP NTNU will instrument both the stationary robots and the AGVs with high-resolution cameras / 3D-cameras and auxiliary sensors to be connected to the 5G network. In addition, the robots and AGVs will be connected using 5G through their traditional interfaces found on external computers and built in through gateways. Here we expect to construct several translations/gateways for proprietary interfaces, OPC UA - as well as ROS 2.0 - based interfaces, as well as additions to AAS components for Industry 4.0.

MTP NTNU will conduct experiments with use of different 5G connections, where measures on KPIs are done both with and without different kinds of welding and other industrial-type operations are done in the labs.

The first scenario at Yara addresses the maintenance expert assistance using AR. Here we will investigate how well the 5G system is capable to support an AR system and transfer of video to the control room / maintenance supervisor. This capability will allow experts to remotely assist the local maintenance experts in performing difficult tasks.

10 This encompasses for example the following uses: production and assembly: Precisely positioned picture-in picture fade-ins, showing the operator the next step and helping to avoid misplacement and unnecessary scrap. Maintenance and repair: Repair machines using augmented information and operational guidance.

The second scenario with Yara - NTNU is using 5G connected devices for monitoring and control. In this scenario we will investigate that the 5G system supports real-time control between geographical separated sites. Such capability allows for remote control and will also give new possibilities for placement of equipment in process control.

5.1.3.3 *UC Architecture*

The overall architecture at NTNU is shown in Figure 13, Figure 14, Figure 15.

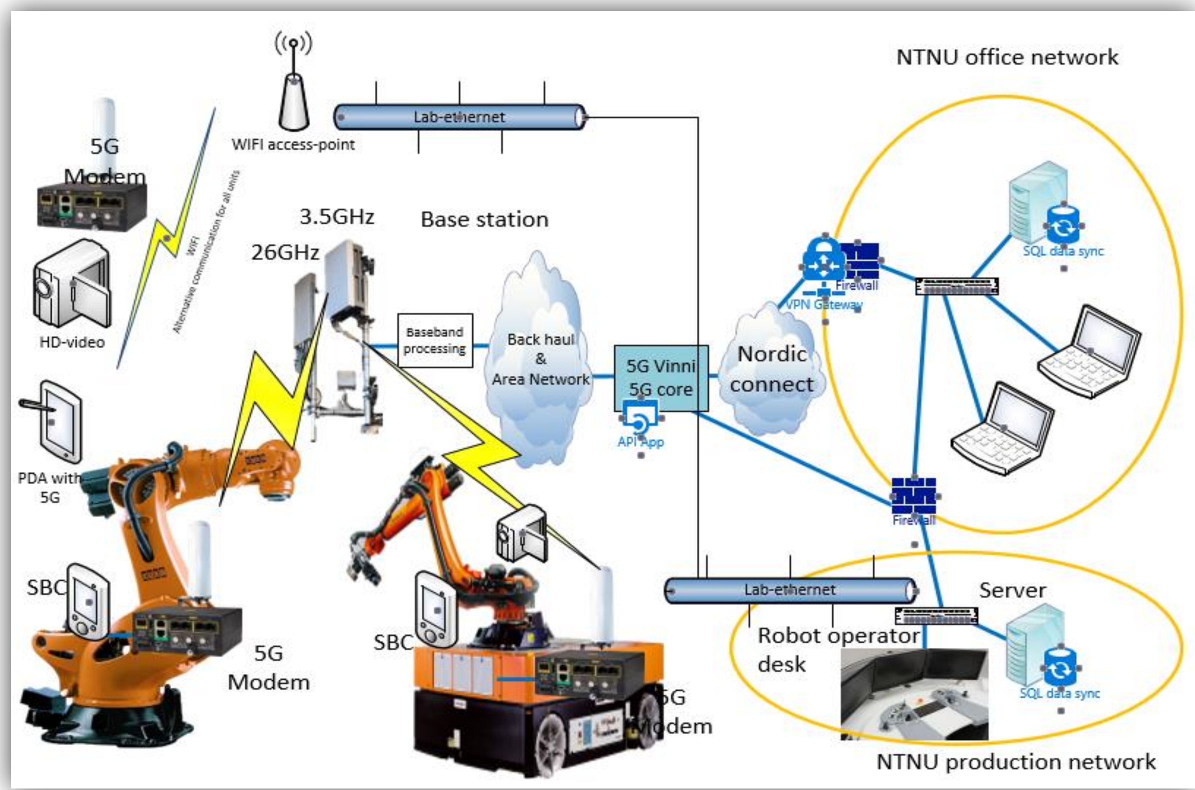

Figure 13: NTNU Lab Architecture used in UC 1.3 / 1.5

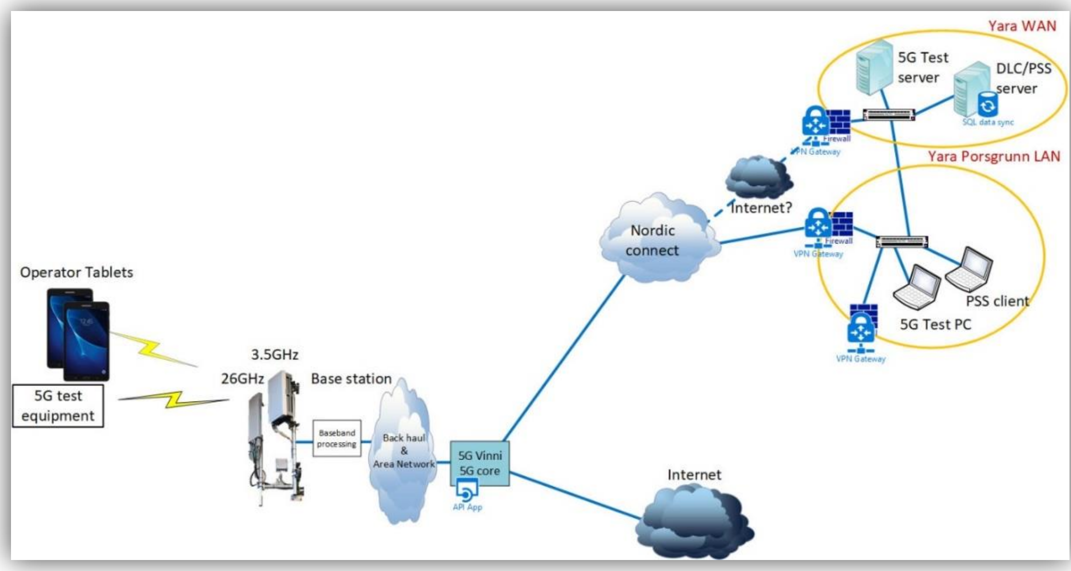

Figure 14: Yara Maintenance expert assistance

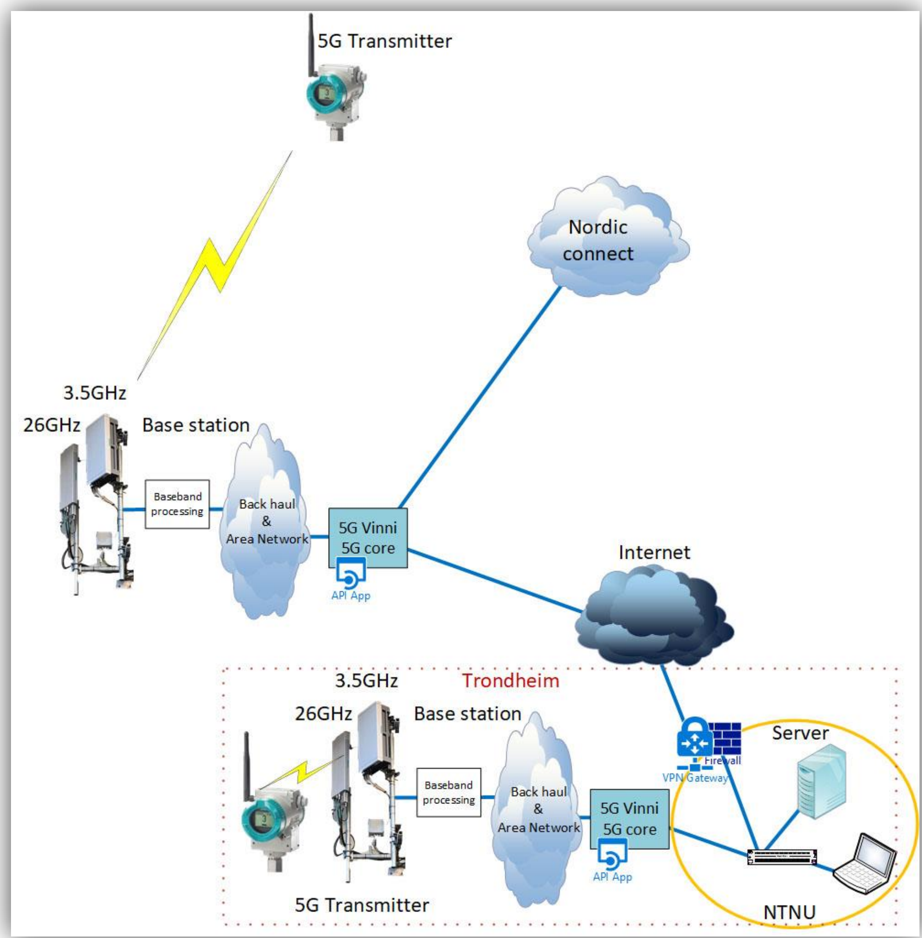

Figure 15: Real-time control geographically separated sites

For the dataflow diagrams to/from end-nodes, measurement equipment and operator desk(s) please see the example in Figure 16.

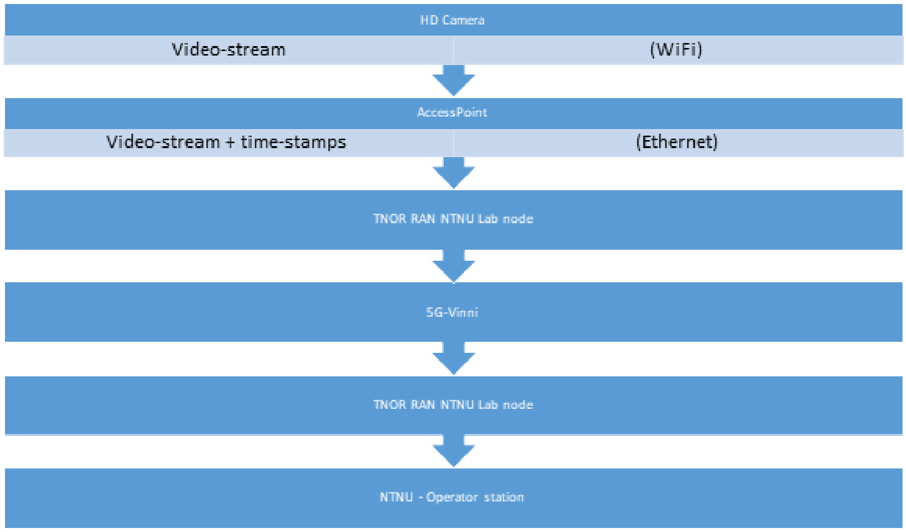

Figure 16: Dataflow - Camera-2-operator (preliminary)

5.1.3.4 Integration with the testbeds and deployment

The overall testing set-up is illustrated in Figure 17. It consists of the following components:

- **The Cross-Domain Service Orchestrator (CDSO)**
  Controls (re-)configuration of the system, starts and stops tests, and notifies the KPI Visualization System about new results being available.
- **The KPI Visualization System (KPI-VS)**
  Retrieves measurement data from the results data base, analyses the data and presents the results.
- **The Results Database**
  For storing measurement results from the tests. The results are pushed to the database both from the TaaS and from the vertical's test set-up.
- **The 5G-VINNI Testing as a Service system (TaaS)**
  A system for performing tests within the 5G-VINNI virtualized network. It can also be used to perform KPI measurements by sending simulated traffic between so called Hawkeye end-points (virtual probes) that can be installed both inside and outside of the 5G-VINNI network.
- **The vertical's application-based test set-up, consisting of:**
  - One or more servers generating application traffic
  - One or more PCs running software that controls the configuration of the tests, starts and stops the tests, and ensures that the measurement results are sent to the results data base. The PC(s) software can be remotely controlled by the CDSO or operated manually.
  - UEs or CPEs that communicate with the 5G network, and which are either connected to the test application server or located on an independent unit (e.g., a robot) sending and/or receiving data associated for example with sensors and actuators.

The test set-up will not be completely implemented for the tests in Cycle 1. More specifically:

- The CDSO will not be used for test case automation. Instead, the tests will be conducted through manual procedures (e.g., for starting and stopping the tests).
- The measurement results from the vertical's application-based test set-up will not be automatically pushed to the results data base. This will instead be done manually.

- The integration between the 5G-Solutions KPI Visualization System and the 5G-VINNI TaaS system will only be partly implemented.

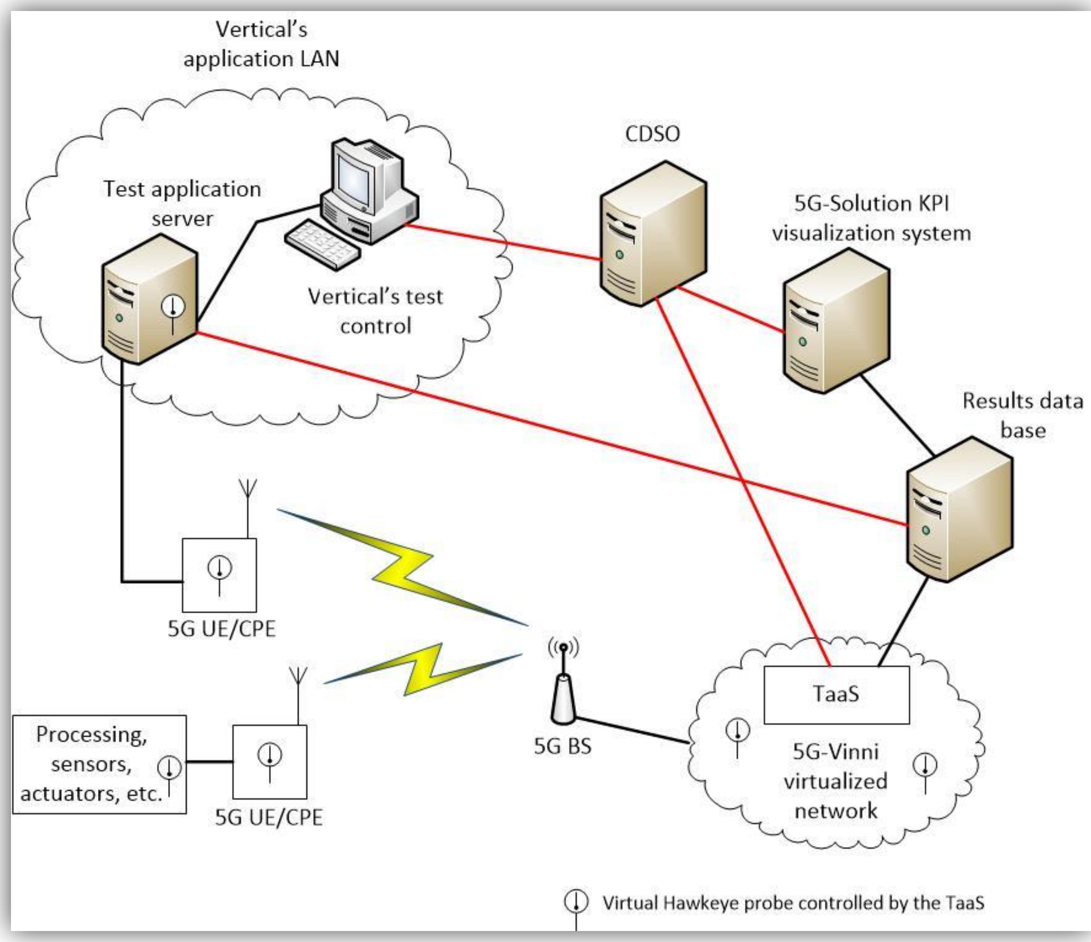

Figure 17: UC1.3 Overall testing set-up

The black and red solid lines indicate message exchange between components. The message exchanges indicated by red solid lines will not be implemented in Cycle 1.

5.1.3.5 *Overall setup and trials plan*

In cycle 1 we will provide a preliminary best effort setup and testing, with only some early performance and feasibility testing of the 5G system. This is also dependent on the private 5G RAN node being made available in due time. Regardless of this, some baseline experiments will be made using existing non-5G technologies for later comparisons. Some of the initial tests will use the commercial 5G system where available, and later be connected to the 5G-VINNI system, which enables test of the performance with a 5G Standalone Core system.

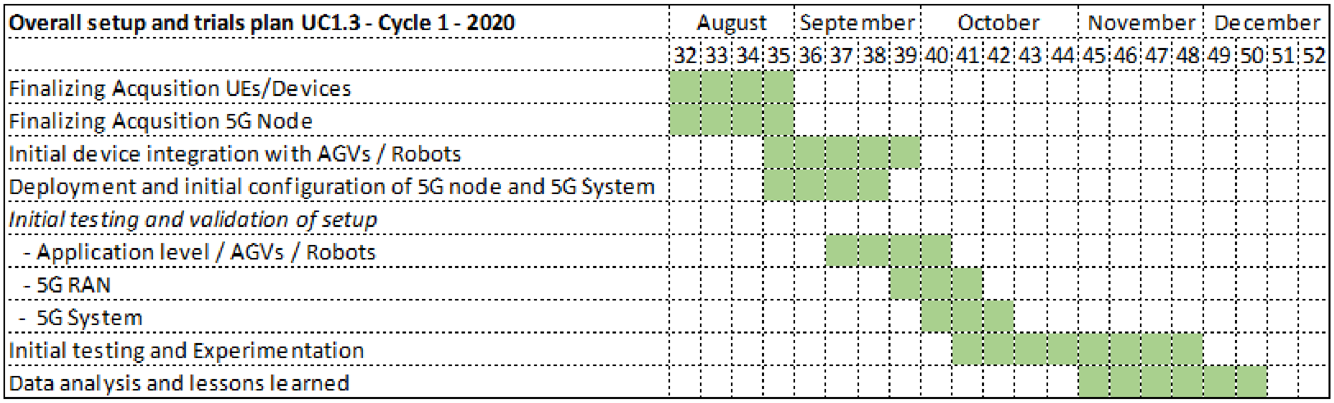

Figure 18: Overall setup and trials plan UC1.3

5.1.3.6 *Testing and experimentation planning*

In the following table the relation between UC-S and TC is depicted. "X" means to be done as initial experiments/testing in October/November. "L" means in cycle 2.

Table 13: Testing and experimentation planning

TC / UCS	UC-S 1.1	UC-S 1.2	UC-S 2.1	UC-S 2.2	UC-S 3.1	UC-S 3.2
UC13_TC1 Throughput UL Video-streams UI	**X**	**L**	**X**	**L**	**X**	**L**
UC13_TC2 Throughput DL Video-streams UI	**X**	**L**	**X**	**L**	**X**	
UC13_TC3 Throughput UL Sensor data	**L**	**L**	**X**			
UC13_TC4 Throughput DL Sensor data	**L**		**X**			
UC13_TC5 latency	**L**		**L**	**L**	**L**	**L**
UC13_TC6 Number of devices simultaneously connected	**L**					
UC13_TC7 Positioning accuracy	**L**		**L**			
UC13_TC8 Indoor Communication Range	**X**		**X**		**L**	
UC13_TC9 Reliability	**L**	**L**	**L**	**L**	**L**	**L**

In week 41-48/2020 the initial testing and experiments are planned to take place. The order will be:

- UC13_TC8
- UC13_TC1 (for UC-S 2.1)
- UC13_TC2 (for UC-S 2.1)
- UC13_TC1 (for UC-S 1.1)
- UC13_TC2 (for UC-S 1.1)
- UC13_TC1 (for UC-S 3.1)
- UC13_TC2 (for UC-S 3.1)
- UC13_TC3 (for UC-S 2.1)
- UC13_TC4 (for UC-S 2.1)

5.1.3.7 *Planned KPIs to be tested*

The most relevant issues and parameters, i.e., KPIs to measure/study for each UC 1.3, are directly measurable quantities such as positional accuracy, latency, reliability, availability of bandwidth etc. in the presence of extensive and unpredictable radio noise caused by electric welding, other electric equipment, reflections and blocking walls and equipment.

Table 14: Planned KPIs to be tested

KPI	Target	Measurement method/formula
Throughput UL Video-streams UI	> 1Gbps	Data-flow monitoring
Throughput DL Video-streams UI	Order of Mbps	
Throughput UL Sensor data	Order of Kbps	
Throughput DL Sensor data	Order of Kbps	
latency	< 10 ms	Timestamping difference
Number of devices simultaneously connected	>10	
Positioning accuracy	< 0,2m	Comparison to manual measures / comparison other indoor location systems
Indoor Communication Range	Between 10 and 30 meters	RSSI at the receiver
Reliability	99.99%	% of data delivered without data corruption

5.1.4 UC1.5: Rapid deployment auto/re-configuration testing of new robots

5.1.4.1 *UC test objective & design*

While in UC1.1, UC1.2 and UC1.3 the RAN properties of the 5G communication are being tested and evaluated in various settings and with different requirements, UC1.5 focuses on the possibility of utilizing the core functionalities of 5G in order to achieve one major feature of Industry 4.0 in the FoF, such as significantly lower expenses and reduced time in order to either commission or reconfigure the robotized manufacturing.

In UC1.5 the goal is to demonstrate how to achieve deployment of new robots into existing plants through automatic on-boarding of industry requirements. This encompasses auto-configuration of (mobile) robots, and the corresponding 5G service configuration needed for interconnection / interworking across solutions from different vendors.

Other overall issues that will be researched in UC 1.5, in cooperation with work in UC1.1, UC1.2 and UC1.3 include:

- To decide upon whether 5G can be utilized to improve the competitiveness of industry, here exemplified with small and medium-sized enterprises e.g., as they typically are in the western part of Norway.
- To get experiences of whether 5G technically and practically can be a replacement at all or some levels, and to which degrees, for the plethora of contemporary proprietary WSNs, proprietary real-time extensions for Ethernet and protocols with their resulting complexity.

- To get experience on how or whether 5G can complement and be used as part of or in conjunction with the other major industrial driving forces of today, mainly the Industry 4.0 initiatives.

The following use case scenarios (UCS) will be studied in this UC:

- UC 1.5_UC-S_1 Deployment through automatic on-boarding
    - UC-S 1.5_1.1 Initial configuration of total system
    - UC-S 1.5_1.2 Setup and execution of Manufacturing procedure 1
- UC 1.5_UC-S_2 Reconfiguration through automatic on boarding
    - UC-S 1.5_2.1 Partial reconfiguration of total system
    - UC-S 1.5_2.2 Setup and execution of Manufacturing procedure 2
- UC 1.5_UC-S_3 Automatic inclusion of new sensors in IIoT system
    - UC-S 1.5_3.1 Inclusion of new sensors
    - UC-S 1.5_3.2 Presentation of data from sensors in the local PIMS system

This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.1.4.2 *UC test design*

The experiments will mainly be performed at MTP NTNU where there are several industrial scales, physically and logically interconnected robotics laboratories being built as of the summer 2019. These are part of the NFR (Norwegian Research Council) supported initiative Manulab[11]. These laboratories at MTP at Gløshaugen in Trondheim consists of several interconnected parts, a general robotics laboratory for welding, one for use with robotized direct construction of casting-forms, stations for automated shaping of metallic pipes and a section with several smaller robots and operator stations to study Industry 4.0 concepts, this especially in conjunction with the AGV lab. See the following figures for an overview.

Figure 19: Robots for welding, milling and grinding

[11] https://www.ntnu.edu/ivb/manulab

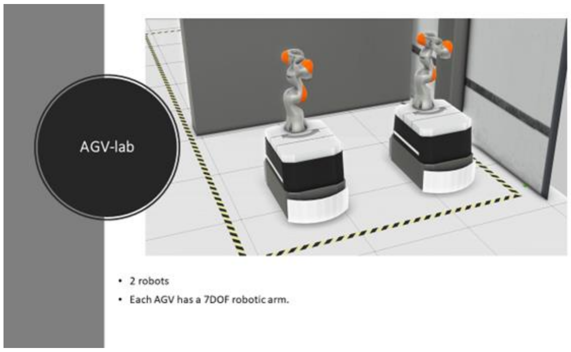

Figure 20: AGV-lab

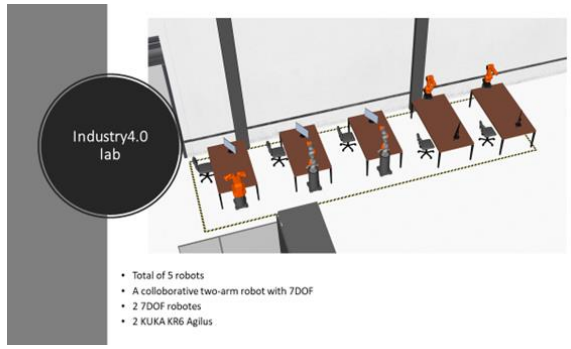

Figure 21: Industry 4.0 Lab

One UC scenario to be done at Yara Porsgrunn is called “Narrow band IIoT”. In this scenario we will test if the 5G system is capable of automatic (or degree of) inclusion of additional installed sensors at the site and to present this information in the local PIMS system. This scenario will need a local connection to the Yara Porsgrunn network, so the information is available for the systems that need to access the information (see Figure 22).

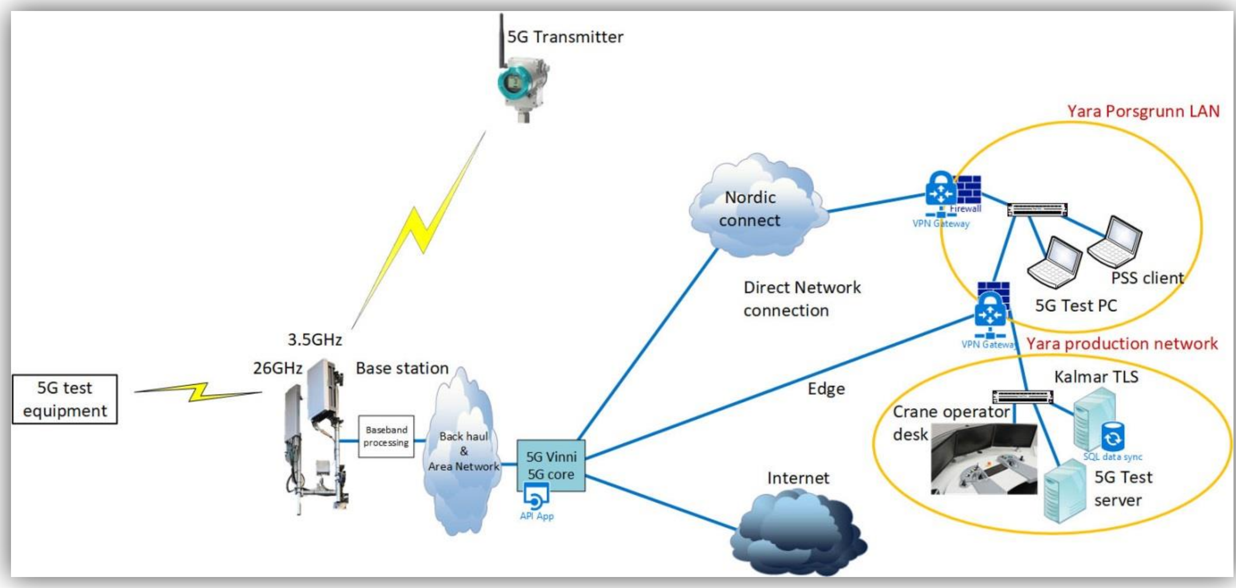

Figure 22: Yara IIoT inclusion test architecture

5.1.4.3 *UC Architecture*

The overall architecture is shown in Figures Figure 13 and Figure 23.

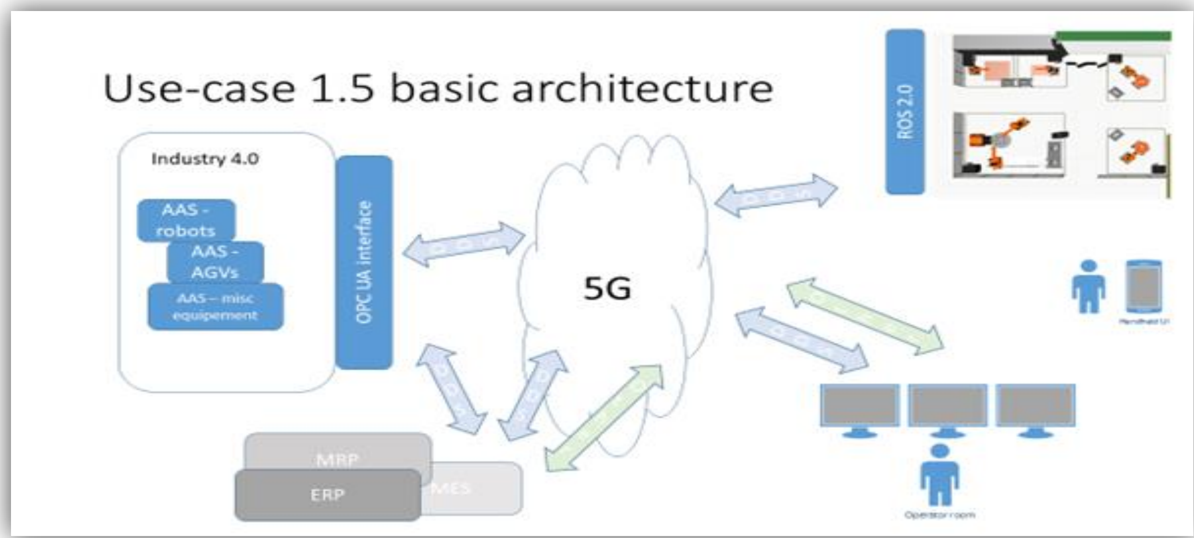

Figure 23: UC1.5 architecture

5.1.4.4 *Integration with the testbeds and deployment*

The overall testing set-up is illustrated in Figure 24. It consists of the following components:

- **The Cross-Domain Service Orchestrator (CDSO)**
  Controls (re-)configuration of the system to test, starts and stops tests, and notifies the KPI Visualization System about new results being available.
- **The KPI Visualization System (KPI-VS)**
  Retrieves measurement data from the results data base, analyses the data and presents the results.
- **The Results Data Base**
  For storing measurement results from the tests. The results are pushed to the database both from the TaaS and from the vertical's test set-up.
- **The 5G-VINNI Testing as a Service system (TaaS)**
  A system for performing tests within the 5G-VINNI virtualized network. It can also be used to perform KPI measurements by sending simulated traffic between so called Hawkeye end-points (virtual probes) that can be installed both inside and outside of the 5G-VINNI network.
- **The vertical's application-based test set-up, consisting of**
  - One or more servers generating application traffic
  - One or more PCs running software that controls the configuration of the tests, starts and stops the tests, and ensures that the measurement results are sent to the results data base. The PC(s) software can be remotely controlled by the CDSO or operated manually.
  - UEs or CPEs that communicate with the 5G network, and which are either connected to the test application server or located on an independent unit (e.g. a robot) sending and/or receiving data associated with e.g. sensors and actuators.

The test set-up will not be completely implemented for the tests in Cycle 1, this includes:

- The CDSO will not be used for test case automation. Instead the tests will be conducted through manual procedures (e.g. for starting and stopping the tests).
- The measurement results from the vertical's application-based test set-up will not be automatically pushed to the results data base. This will instead be done manually.

- The integration between the 5G-Solutions KPI Visualization System and the 5G-VINNI TaaS system will only be partly implemented.

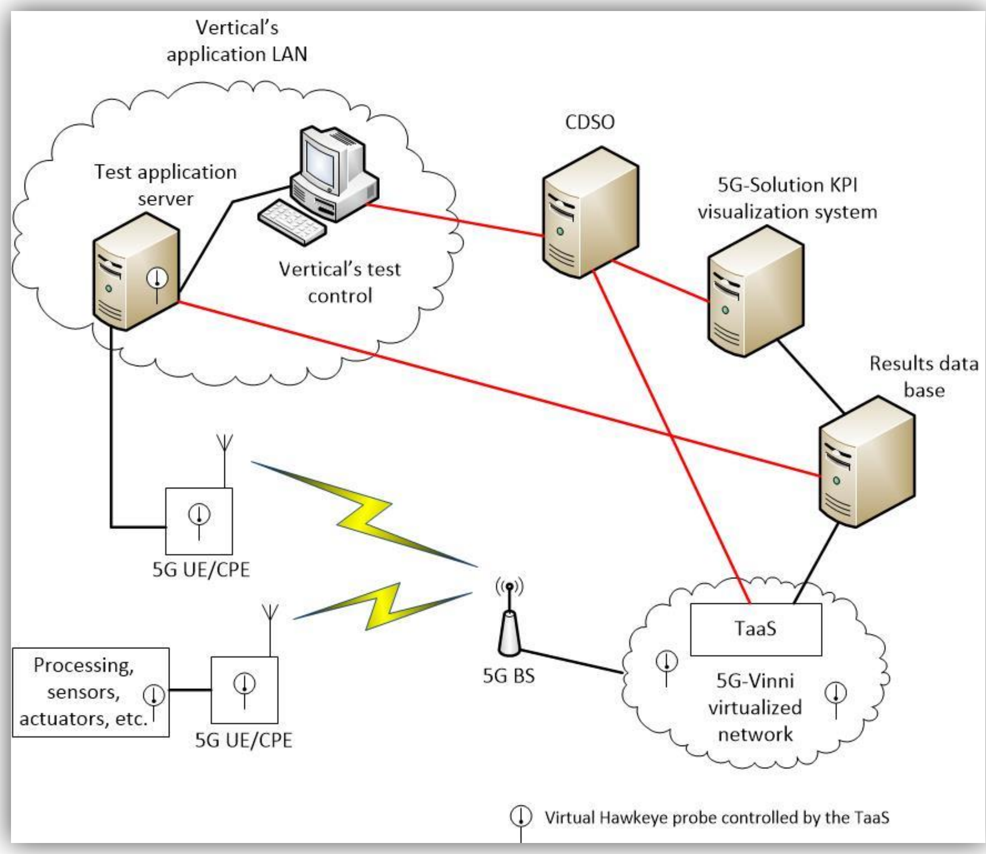

Figure 24: Overall testing set-up

The black and red solid lines indicate message exchange between components. The message exchanges indicated by red solid lines will not be implemented in Cycle 1.

5.1.4.5 *Overall setup and trials planning*

In cycle 1 it is mostly about best effort and there will only be performed some early feasibility and performance testing of the 5G system. This stands, under the presumption that the private 5G RAN node is made available in due time. Regardless of this, baseline experiments will be made using existing non-5G technologies for later comparisons. Some of the initial tests will use the commercial 5G system where available, and later be connected to the 5G-VINNI system, which enables test of the performance with a 5G Standalone Core system.

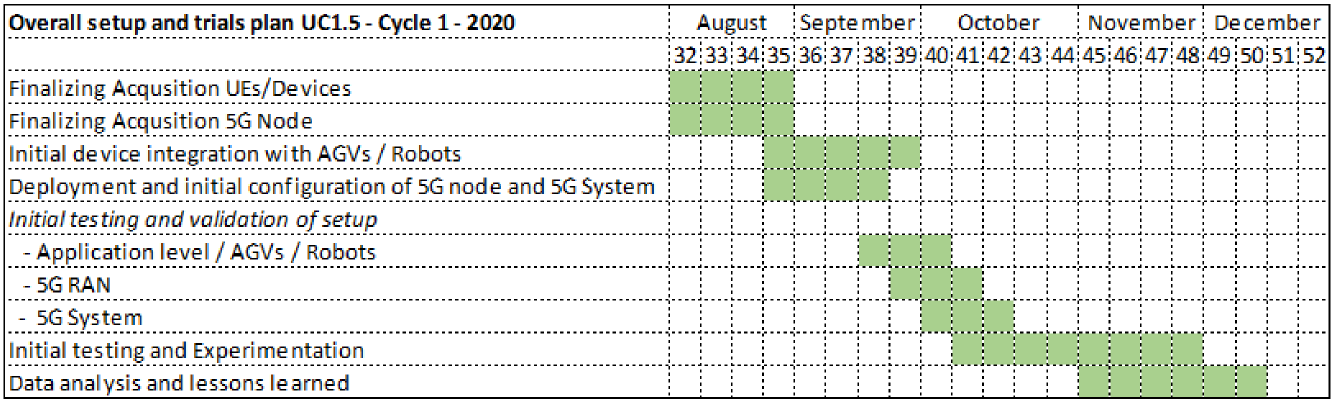

Figure 25: Overall setup and trials planning UC1.5

Critical tasks that will be studied over all cycles include:

1. Possibility of increased level of automation and usage of robots being achieved by eased set-up and configuration reduced time, effort and cost for this, through leveraging of 5G-technologies.
2. Improved flexibility in the use of the aforementioned equipment due to the previous point.
3. To find out whether, and if, how, information in so-called AAS (Asset Administrative Shell) can be utilized optimally, or even practically, to set up the necessary resources in a (possibly shared) 5G infrastructure.
4. Study the compatibility/co-operation and co-existence issues of 5G with several of the lower-level technologies that can be expected to be part of Industry 4.0:
    4.1. OPC UA (With DDS)
    4.2. Industrial Internet Reference Architecture (IIRA)
    4.3. ROS 2.0 (based on DDS as middleware)
5. Whether 5G can substitute traditional network-technologies, especially in a scenario where resources are shared, even with unrelated parties, therefore reducing the need for in-house competence in various networking technologies. This bullet point can be related to the KPIs directly.

These tasks will be further developed over cycle 1 and future cycles.

5.1.4.6 *Testing and experimentation planning*

In the following table the relation between UCS and TC is depicted. "X" means to be done as initial experiments/testing in October/November. "L" means in cycle 2.

Table 15: Testing and experimentation planning

TC / UCS	UCS 1.1	UCS 1.2	UCS 2.1	UCS 2.2	UCS 3.1	UCS 3.2
UC15_TC1 Throughput UL Video-streams UI					**X**	**L**
UC15_TC3 Throughput UL Sensor data					**X**	
UC15_TC5 latency					**L**	**L**
UC15_TC6 Number of devices simultaneously connected	**L**		**L**		**L**	
UC15_TC8 Indoor Communication Range	**X**		**X**			
UC15_TC9		**L**		**L**	**L**	**L**

Reliability						
UC15_TC10 Availability of parameters for networking	**X**	**X**	**L**	**L**	**X**	**L**
UC15_TC11 Compatibility of interfaces	**X**	**X**	**L**	**L**	**X**	**L**

Table 16: Testing and experimentation planning

In week 41-48/2020 the initial testing and experiments are planned to take place. The order will be:

- UC15_TC8
- UC15_TC10 (for UCS 1.1)
- UC15_TC10 (for UCS 1.2)
- UC15_TC10 (for UCS 3.1)
- UC15_TC11 (for UCS 1.1)
- UC15_TC11 (for UCS 1.2)
- UC15_TC10 (for UCS 3.1)
- UC15_TC1 (for UCS 3.1)
- UC15_TC3 (for UCS 3.1)

5.1.4.7 *Planned KPIs to be tested*

For the most relevant parameters, i.e., KPIs to measure/study for each UC (1.1, 1.2, 1.3 and 1.5), some are purely qualitative such as “feasibility of using an infrastructure delivered by an external vendor such as Telenor for industrial purposes”. Others are more directly measurable quantities such as the aforementioned positional accuracy, latency, reliability, availability of bandwidth etc. in the presence of extensive and unpredictable radio noise caused by electric welding, other electric equipment, reflections and blocking walls and equipment.

While the indicated performance will be needed for UC1.5, latency, reliability and bandwidth-availability will be focused on in UC1.1 and UC1.2. These both on a low “instrumentation” level, as well as when used for covering several of the traditional industrial levels for networks. The latter done with organization of virtual networks.

This is also the case for the measures of positional accuracy which will be reported in UC1.3. Here this is to be used with AGVs for production purposes. For UC1.3 also the reliability and timeliness of the achieved accuracy in this assumed-to-be-difficult environment will be reported.

Table 17: Planned KPIs to be tested

TC / UCS	UCS 1.1	UCS 1.2	UCS 2.1	UCS 2.2	UCS 3.1	UCS 3.2
UC15_TC1 Throughput UL Video-streams UI					**X**	**L**
UC15_TC3 Throughput UL Sensor data					**X**	
UC15_TC5 latency					**L**	**L**
UC15_TC6 Number of devices simultaneously connected	**L**		**L**		**L**	
UC15_TC8 Indoor Communication Range	**X**		**X**			
UC15_TC9 Reliability		**L**		**L**	**L**	**L**
UC15_TC10	**X**	**X**	**L**	**L**	**X**	**L**

Availability of parameters for networking						
UC15_TC11 Compatibility of interfaces	**X**	**X**	**L**	**L**	**X**	**L**

5.2 LL2: Smart Energy

The Living Lab Smart Energy presents three use cases for trial Cycle 1, Cycle 2, and Cycle 3. The use cases have been analyzed from the technical and business point of view in D1.1A. In this section all available information concerning the use case set up, planning, implementation and deployment are reported according to the status at the end of the Cycle 1 (June 2021, according to last Contract Amendment). The GANTT charts show the actual plan of the activities for the following months of the project.

The workflow is designed in three distinct consecutive cycles. Each cycle is built upon the results and outcomes from the previous one. Each cycle represents a key step for reaching, at the end, the complete end-to-end test case execution on the field. In Cycle 1 the main focuses will be on pre-trial aspects and basic software and hardware component related aspects, including the onboarding of available Vertical Services as VNF chains in the 5G platform, namely 5G EVE. In Cycle 2 the attention will be moved on the integration of all software and hardware components developed to execute the test case on the field. Finally, in Cycle 3 by exploiting previous results and analysis, the objective will be to close the chain by integrating software, hardware and infrastructure components with the goal of performing the complete use case in a near-real-word environment.

All information reported here is the output of the fruitful and continuous cooperation among all partners involved in this Living Lab, namely Enel X, Iren, Ares2t with the Linked Third-Party CRAT.

5.2.1 UC2.1: Industrial demand side management

5.2.1.1 *UC test design*

In Cycle 1, two kinds of test cases are defined for UC2.1: *integration test* for ICT standalone LL software components and *pre-trial test* for 5G connectivity in the Test Sites to support communication among the relevant hardware and software components. The Test Site in Turin (Italy) will be covered by the Italian Site of the ICT17 5G EVE platform. Pre-trial 5G connectivity tests aim at determining on-field network KPI values related to network coverage, reliability, and latency.

The **reference scenario** for test cases in Cycle 1 is the *pre-trial and integration test* one. **Test areas** of interest in Cycle 1 are:

- *Main electrical load (heat pump and other energy loads) test area preparation* to test the integration of the energy facility (basically Heat Pump control and measurement integration) with 5G infrastructure (i.e., Cloud Edge environment) of the Italian Site of the ICT17 5G EVE platform for test cases 2.1.1 and 2.1.2;
- *Dispatching Market and Local BMS (Building Management System) Optimizer integration simulation area* to test the interaction between the Vertical Service as well as all necessary VNFs that will be defined and onboarded on the Cloud Edge environment of ICT17 5G EVE platform (back-end side) and the mobile device running the client application (front-end side) for test case 2.1.3.

5.2.1.2 *UC Test Planning*

The reference GANTT for UC 2.1 is depicted in Figure 26. In Cycle 1 an algorithm for the electrical loads aggregation and management will be designed and simulated to develop a Vertical Service which opens the Balance Service Provider to the participation in the Dispatching Market in line with the architecture introduced in the following sections.

During the setup and execution of test cases for Cycle 1, we developed the *ad hoc* control algorithm for the use case and performed preliminary simulations on 5G-network-independent systems. The over-mentioned algorithm will be designed based on the real-operational conditions at the site of installation, taking into account the limitations related to the indoor operational environment.

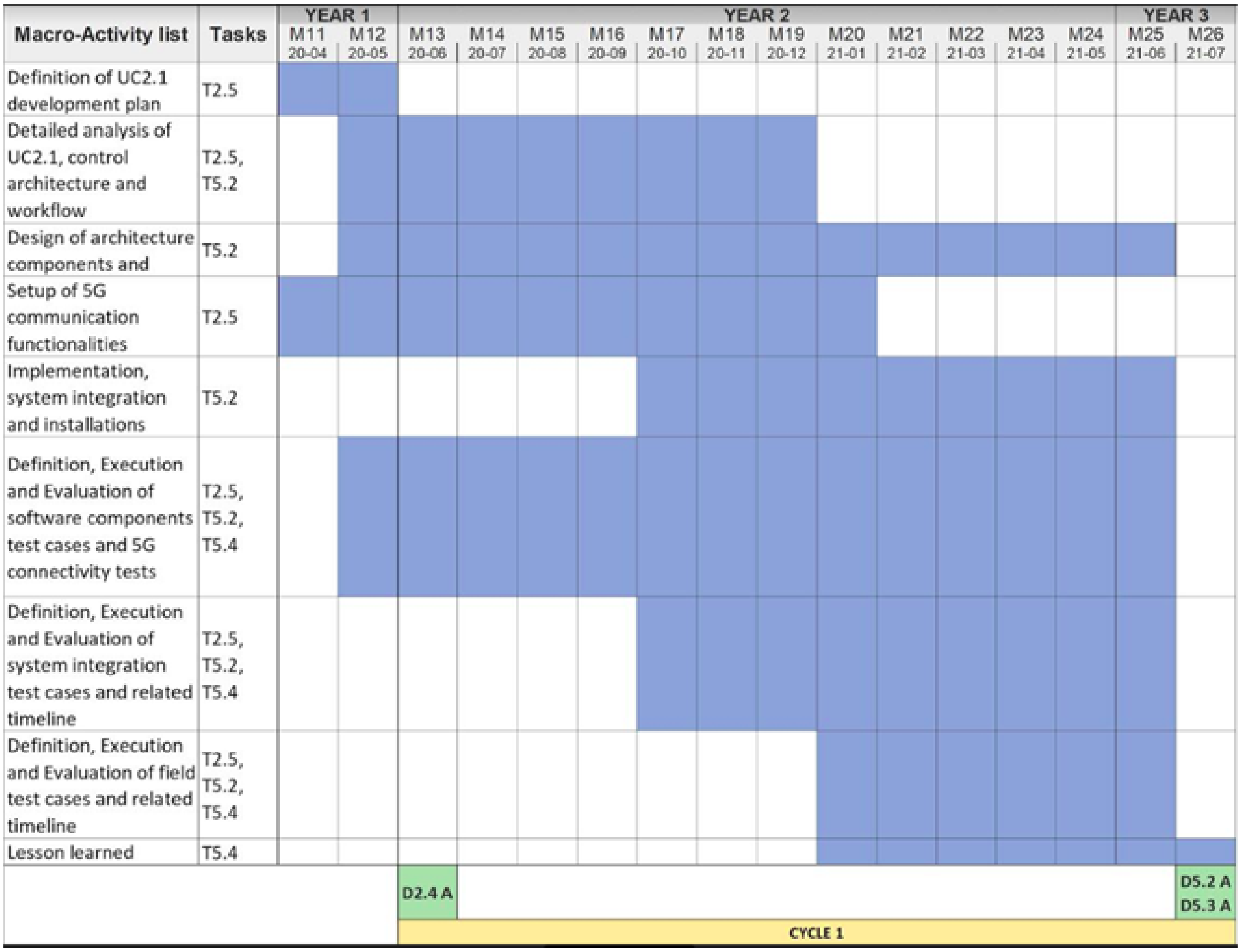

Figure 26: UC2.1 – GANTT – Cycle 1

5.2.1.3 *UC Architecture and Information flow*

The architecture specification starts from the complete list of the components that will play a role in the use case and related test cases planned from Cycle 1 to Cycle 3. The use case has been decomposed in three test cases, namely TC 2.1.1, TC 2.1.2 and TC 2.1.3. In this section we will not consider a pre-trial test case TC 2.1.0 that is dealt as part of the 5G facility set up and test. For each of them, the Use Case owner and the Use Case Developer indicated a list where each component is described and related activity (e.g., installation, configuration, connection, etc.) is reported.

After the description of the test cases, the reference control architecture and a preliminary message sequence chart involving the KPI Visualization System are presented and explained.

TC 2.1.1: Heat Pump and Remote Monitoring and Control Unit (RMCU) communication to the Aggregator Remote Transmission Unit (RTU) with the aim of testing the 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 Battery Management System (BMS). Main components include:

- Installation of innovative Heat Pump system (190 KWt), in substitution of one chiller (out of 5G-SOLUTIONS project budget, synergies with H2020 project "PLANET")
- Heat production during winter period supporting existing methane boiler
- Installation of a new heating storage for a better exploitation of the HP system
- Integration of the HP in the existing heating/cooling distributions system
- Building RMCU (Remote Monitoring and Control Unit) enabling near real time building electric consumption data pushing to the Aggregator RTU. Prototype 5G communication embedded will be tested
- 5G communication of the Heat Pump PLC to the RTU and/or the control and thermoregulation system (BMS)

TC 2.1.2: Electrical monitoring and/or comfort monitoring devices integration in the energy management system with the aim of testing 5G communication (compared to 4G) in terms of reliability, flexibility and speed/latency when pushing consumptions 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. Main components include:

- Installation of new electrical monitoring system (post-fiscal meters) to supervise main electrical consumption at building and HP level
- Installation of new comfort monitoring sensors to integrate building comfort measurements

TC 2.1.3: Reactive load disconnection for black-out avoidance with the aim of testing 5G communication (compared to 4G) for latency when applying for load disconnection to avoid blackout. The third test case is composed by two main components, interacting each other: the **Proof of Concept** (PoC) and the **Remote Controller** (RC). The PoC has hardware and software components, while the RC has software components only. The specific hardware components of PoC are:

- Schuko male 16A
- Electraline 80868, 32A, 2P+T, 220V, Blue
- Modular contactor 20 A 220 V
- Shelly 1 (16A WiFi breaker)
- USB Power supply
- Shelly 1 PM (16A WiFi breaker + power meter)
- Shelly EM + 2 Clamps (32A WiFi power meter)
- Outlet 16A 220 V
- Breaker + Differential
- Raspberry Pi 4
- Outlet 32 A
- Relay 32 A
- Schuko female 16 A
- DIN Bar
- Gewiss Box
- Micro SD 64GB SanDisk

5.2.1.3.1 Reference architecture

Once test cases and related hardware components have been identified, the reference architecture has been developed. The resulting high-level scheme of Use Case 2.1 is reported in Figure 27. Each test case will rely on this architecture, while some of them will require further refinements according to the following sections dedicated to each test case.

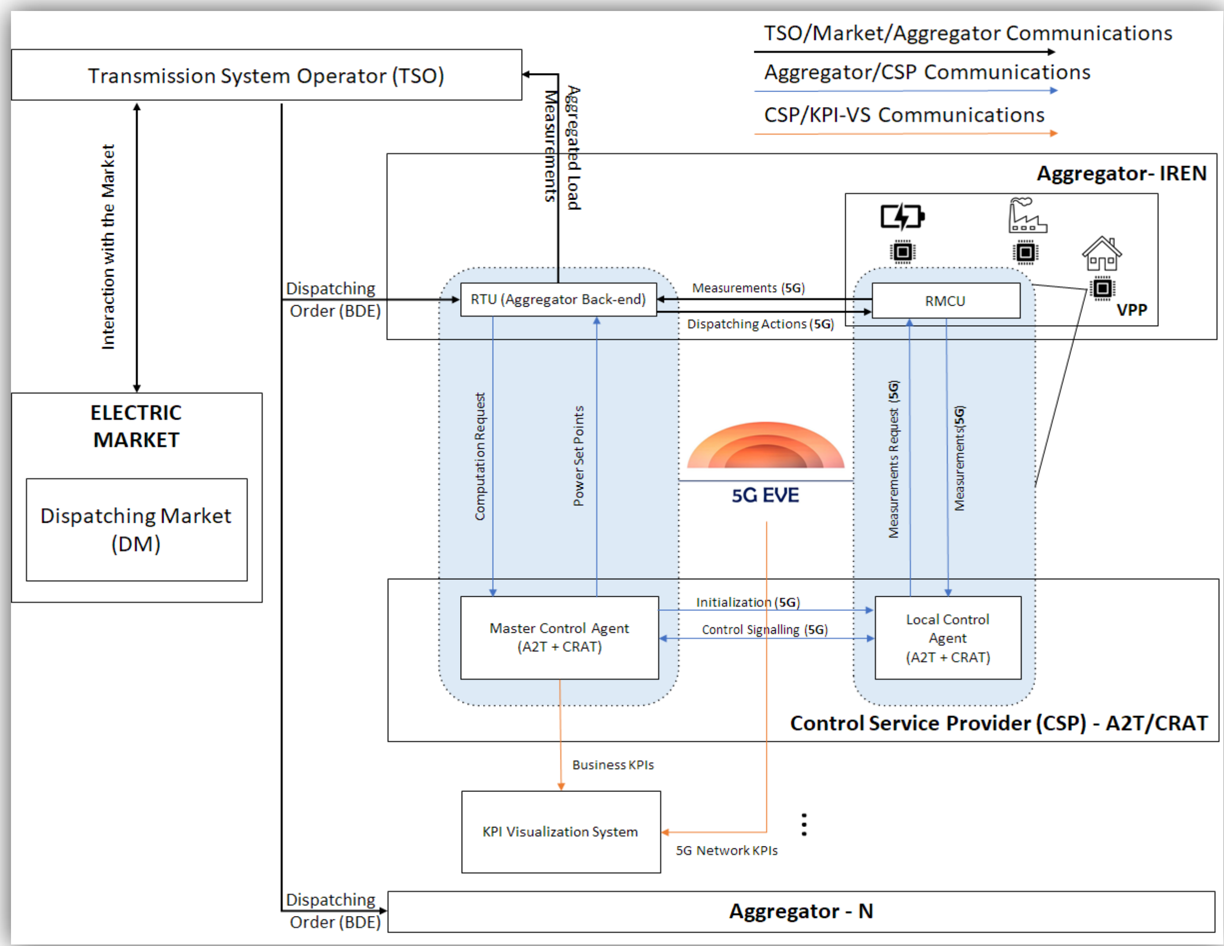

Figure 27 UC2.1 – Reference architecture for UC 2.1

TC 2.1.1

The goal of TC 2.1.1 is to show how 5G technologies can facilitate the involvement of new actors in the Dispatching Market (DM), with the extension of the Demand Side Management (DSM) paradigm not only to medium/large production/load units (that are fixed by the previous TSO's regulations to be at least 10MVA), but also to owners or managers of smaller loads, which, if aggregated, are able to form a Virtual Power Plant (VPP) with scalable capacities, with the effect of increasing the competitiveness. Demand Side Management included the set of actions needed to adapt the energy production/consumption (or even both of them in more general scenarios) of a generation/load site in order to reduce the cost of energy production, to reduce network losses or in general to help the overall network to work in a more efficient way. As a result of the high penetration of renewable sources and the decentralization of production sources, network managers of many countries are facing the problem of the increasing instability of their networks and the consequent disservices for users. To limit these impacts and ensure the balance between consumption and energy input into the network, network operators can rely on generation and consumption units offering remunerated "network services". An effective solution to poor flexibility can be to "decentralize", i.e., to make use of several different loads and production units, potentially in continuous evolution. In fact, a central control strategy is not able to guarantee the needed flexibility and, at the same time, the possible huge number of aggregated actors required to form a VPP would require important computation capability, with the associated cost.

It is possible to identify three layers of competence:

- Transmission System Operator (TSO) Layer
- Aggregator Layer
- Control Service Provider (CSP) Layer

The overall control architecture is supported by the presence of the Italian Site of ICT17 5G EVE Facility that allows configuring a test case supported by a dedicated 5G network through web access to the 5G EVE Portal.

The architecture is composed of the following operational blocks and entities:

- The 5G EVE block that represents the 5G infrastructure offered by the 5G EVE Turin Test Site.
- The Transmission System Operator, which is an external part, has the capabilities to send dispatching orders that can modify the operational conditions. These dispatching orders are sent to the Aggregator layer, in particular to the Remote Terminal Unit (RTU). The TSO, according to the deliberation 422/2018/R/EEL of ARERA, receive with an interval of 4 seconds, the VPP aggregated load measurement.
- The Aggregator Layer collects two main entities:
    - The Remote Terminal Unit (RTU) that encloses the back-end system of the operator. This block is design to cover a multiplicity of tasks, indeed is in charge of works as interface between all the layers, it is in charge of receiving: dispatching orders, measurements from the field and the power setpoint that has to be actuated on the flexible loads, send charging requests to the Control Service Provider and the actuation signals to the field device;
    - The Virtual Power Plant (VPP) is composed by the flexible load and Remote Monitoring Control Units (RMCUs). RMCUs are devoted to the communication with the RTU in order to send electrical measures and perform electrical actuation actions, they communicate also with the distributed part of the Control Service Provider, the Local Control Agents, to provide the measurement needed for the computation of optimal setpoints.
- The Control Service Provider (CSP) Layer encloses the operational blocks that allow to provide the services needed to participate to the Dispatching Market. In this layer we can identify two operational blocks:

    - The Master Control Agent is a central node of the distributed architecture of the CSP. It is in charge of communicating with the RTU to receive requests of the service and to communicate the optimal setpoints that should be actuated. The Master Control Agent interacts with the KPI Visualization System in order to allow the visualization of both business and technological KPIs. Finally, it is connected as central node of a star topology with the Local Control Agents, the Master Control Agent initializes all the Local Control Agents to perform the computations and iteratively exchanges control signaling with them to reach the result of the control algorithm.

    - The Local Control Agents are the distributed components of the CSP layer. Their main role is the computation of local optimization problems. Their results will be used to compute the optimal power setpoints. They communicate with RMCUs to obtain the measurements needed for the computation and with the Master Control Agent (with what is called Control Signaling) to take part in the overall control algorithm.

The proposed architecture is structured in a way to exploit the above-mentioned control decentralization; as indicated in the figure, the Transmission System Operator (TSO) takes measurements of aggregated loads from the Aggregator participating to the MD through the Remote Terminal Unit (RTU set of actions needed to comply with the Dispatching). <u>In case of network imbalance, the Electric Market strives in order to find some parties that are able to re-balance the network.</u> Once the Market finds the parties and the prices, then the TSO sends a Dispatching Order (BDE) to the Aggregators' RTUs (though IEC 60870-5-104 protocol). Each Aggregator has to determine the adequate Order, within a few minutes (15 minutes according to the current regulations). The strict requirement on the settlement leads the company's research in the direction of the optimal power scheduling in terms of both economical and computational efficiency.

The difficulty of current control architectures to deal with distributed programmable/non-programmable production/consumption sites, forces the switch from centralized control architecture into a decentralized one. In the proposed control architecture, we introduce an additional entity, the Control Service Provider (CSP). CSP is in principle a service provider that exposes external APIs to the Aggregator. In this architecture nothing changes from the TSO point of view, since it continues to exchange messages with the RTU in the usual way, so the new control architecture is fully transparent. The RTU, instead, should be able to interface with the CSP system, which is characterized by 2 main entities: a “Master Control Agent” and a “Local Control Agent”.

After receiving a Dispatching Order from the TSO through the Aggregator, the RTU (that represents the Aggregator back-end) calls proper services exposed by the Master Control Agent. These services orchestrate a series of communications among the Master Control Agent, the RTU and the Local Control Agents. The Master Control Agent gets the Remote Monitoring Control Unit (RMCU) power measures from the RTU and activates each Local Control Agent present in the VPP in order to compute in a distributed way the optimal power target for each of the loads/generators present in the VPP. The computation of such optimal power targets is done through iterative algorithms that at each time step compute an approximate solution until they converge. The number of communications among the Agents can high, especially with a lot of loads/generators (and this is actually the case in VPP), so the communication delay can become an issue in guaranteeing that the new setpoints for loads and generators are computed and actuated within the time provided by the TSO. Moreover, the convergence of the algorithm could be impaired in case there is a loss of control messages.

In order to reduce the communication delay as much as possible (and so give more time for the actual computing and actuation of the new power setpoints) and to guarantee a high level of reliability, the proposed architecture envisages the use of 5G technologies for the communication among the Agents, leveraging on Ultra-Reliable Low-Latency Communication (URLLC) service of 5G communication.

At the end of the computation phase, the Master Control Agent communicates to the RTU the Dispatching Actions, i.e., the new power targets for the loads and generators of the VPP, and the RTU sends these setpoints to the RMCUs, that are in charge of modulating the load/generator power according to the new setpoint. The Master Control Agent is also in charge of communication with the KPI Visualization System.

In Cycle 1 the plan is to evaluate the capabilities and limitations of the real load that will be involved in the next cycles. Specifically, in Cycle 1 the heat pump will be remotely monitored and controlled both in cooling and heating operations; data related to the power consumptions and temperature variations will be collected in view of further activities for UC 2.1 in the next project cycles. The collected data will be taken into account in the next Cycle 2, where an algorithm for the aggregation of flexible loads (including real loads and virtual ones) will be designed according to the described architecture.

TC 2.1.2

The goal of TC 2.1.2 is to complement the features and goals of TC 2.1.1 in getting the most from the field in terms of energy monitoring of all assets and building comfort. The TC could be seen as a stand-alone test case granting a near real time monitoring for building management systems integration or a complementary solution to manage flexibility assets (as the heat pump in TC 2.1.1) in the most efficient way without discomfort or operation problems, focusing on Aggregator flexibility prevision and feedback from the field.

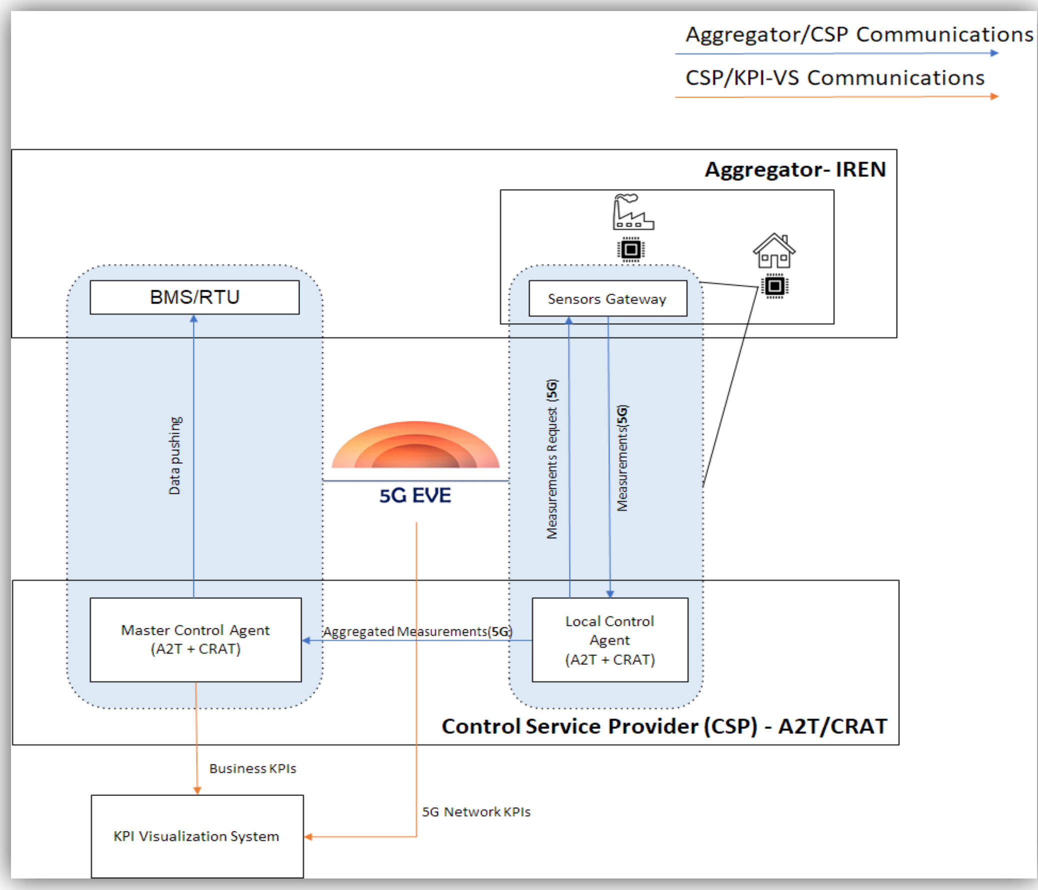

Figure 28 UC2.1 – Reference architecture for TC 2.1.2

It is possible to identify two layers of competence:

- Control Service Provider (CSP) Layer
- Aggregator Layer (not mandatory)

The overall control architecture is supported by the presence of the 5G EVE facility that allows using the 5G network for the communications.

The architecture (Figure 28) is composed of the following operational blocks and entities:

- The 5G EVE block that represents the 5G infrastructure offered by the 5G EVE Facility in Turin as Italian Site.
- Control Service Provider (CSP) Layer, where also the Building Management System could be considered, encloses the operational blocks that allow providing the near real time monitoring data of main electrical loads apart from the flexible ones and indoor monitoring of comfort parameters (mainly temperature, rh, $CO2$). These data will be collected and pushed to the platforms that will need it (BMS, aggregator platforms /RTU, etc.). In this layer we can identify two operational blocks:
    - The Master Control Agent is a central node of the distributed architecture of the CSP, it is in charge to communicate with the RTU or the BMS platform to receive requests of the service and to communicate the aggregated sensors data. The Master Control Agent interacts with the KPI Visualization System in order to allow the visualization of both business and technological KPIs. Finally, it is connected as central node of a star topology with the Local Control Agents;

- The Local Control Agents are the distributed components of the CSP layer, their main role is in the computation of local optimization problems, and their results will be used to compute the optimal power setpoints. They communicate with Sensors Gateways, to obtain the measurements, process them in order to clean and filter the data and send them to the Master Control Agent.

If needed, data could be also pushed to the Aggregator Layer or will remain locally used to monitor the comfort actions put in place.

In this TC, the Control Service Provider (CSP) is in charge of exposing, through external APIs, the field data to BMS or other platforms/systems (e.g., the Aggregator ones).

In order to reduce, as much as possible, the communication delay (and so give more time for the actual computing and actuation of the new power setpoints) and to guarantee a high level of reliability, the proposed architecture envisages the use of 5G technologies for the communication among the field sensors and the CSP, leveraging on Ultra-Reliable Low-Latency Communication (URLLC) service of 5G communication.

TC 2.1.3

The goal of TC 2.1.3 is to show how 5G technologies can foster novel market opportunities for an **Energy Market Operator (EMO)**, minimizing the off-specification time of the **Virtual Power Plant (VPP)** while guaranteeing the continuity of higher priority loads, applying for a real time load shedding. In order to demonstrate how 5G technologies impact on energy market operators, the 5G-SOLUTIONS **KPI Visualization System** helps to compare the **Business KPIs** with the correlated **Network KPIs**. In particular, the Business KPIs focus on the time needed by the system to apply for a rapid load shedding while avoiding a current overload (that can cause a black-out due to the current limits set in the electric meter). The less this time (called *disconnection time*) is, the more the VPP is able to stay within the load specifications, thus being a more predictable and deterministic end user. Having deterministic and predictable end users means to have cost savings associated with the use of Demand Side Management (DSM). In the light of the above, since 5G communications are more reliable and have less latency than 4G communications, the main goal of this test case is to measure in an objective way how the usage of 5G technologies have impact, with respect to 4G, on the possibility to offer better DSM services.

In particular, in the proposed test case, an instance of the UC2.1 architecture must be deployed. As shown in Figure 29, the system architecture is composed by two parts:

1. **Local controller** developed as a **Proof of concept (PoC)** by Ares2T, in charge of acting as a VPP. The PoC interfaces with the VPP sensors (e.g., power meters) and actuators (e.g., switches) by means of a Remote Management and Control Unit (**RMCU**), integrated as hardware part in the PoC, that is controlled locally by a **Local Control Agent** (LCA), integrated as software part in the PoC;
2. **Remote controller** developed by Ares2T, in charge of controlling remotely one or more VPP 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 VPPs and sending back the needed corrective **Actions** to apply for a prompt load shedding; the latter is in charge of elaborating proper load shedding algorithms that find the best disconnection/reconnection strategy.

It is worth noting that the Remote controller can be hosted in any remote facility (e.g., as a cloud service) but, for the purpose of 5G-SOLUTIONS, it will be hosted in the 5G EVE facility in Turin, to catch precise Network KPIs, needed to validate the proposed solution

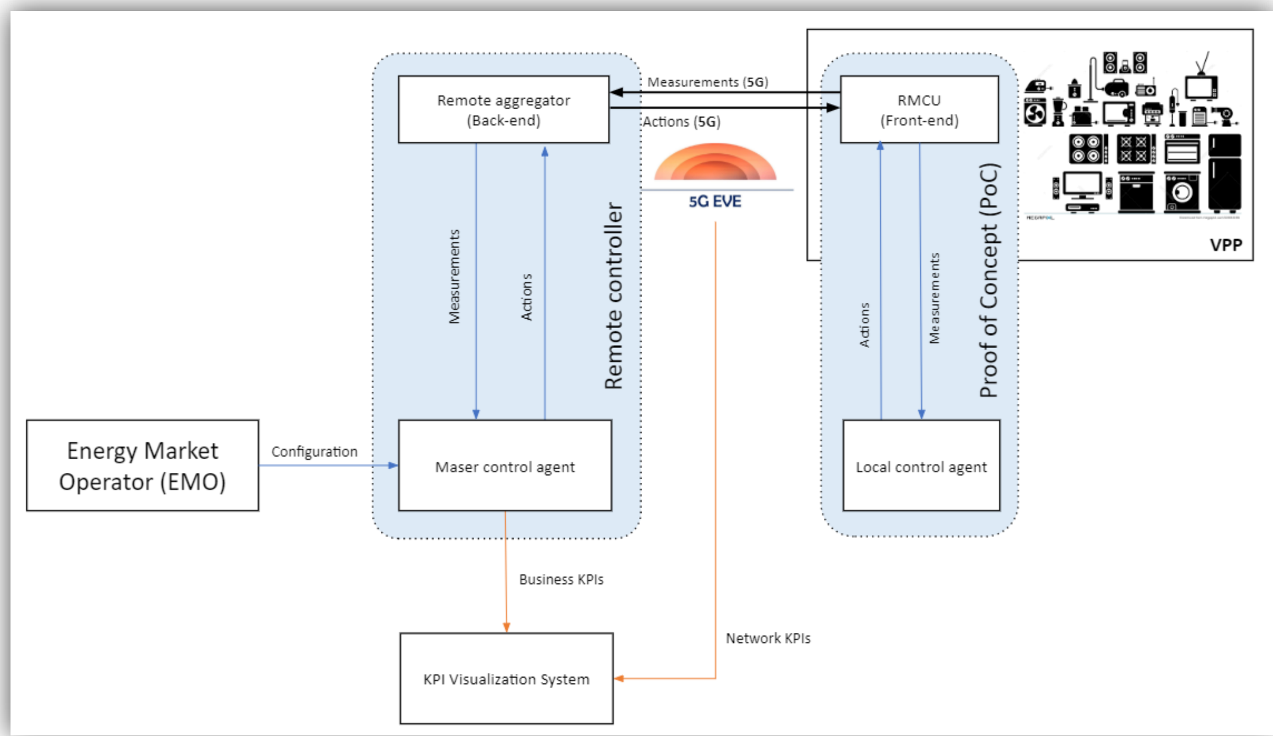

Figure 29 UC2.1 – Reference architecture for TC 2.1.3

5.2.1.3.2 Information sequence diagram

The sequence diagram represents the message exchanges between the different components of the architecture of the UC 2.1. All the arrows in the figure represent information flows and not API calls.

TC 2.1.1

With respect to TC 2.1.1, with reference to Figure 30, the actors are:

- the Experimenter is represented by the Use Case owner (IREN);
- the 5G EVE block represents the 5G infrastructure offered by the 5G EVE Turin Test Site;
- the Transmission System Operator (TSO) is the party in charge of sending Dispatching Orders (BDE) coming from the Energy Market to the Aggregator and to check that the BDE is properly actuated;
- the Remote Terminal Unit (RTU) is the Aggregator Unit in charge of managing the Remote Management Control Units (RMCUs);
- the Master Control Agent is the Control Service Provider (CSP) backend that is in charge of communicating with the RTU and of managing the Local Control Agents;
- the Local Control Agent is the CSP entity in charge of computing, in a distributed way and with the other Local Control Agents and the Master Control Agent, the active demand product composition for the Aggregator Virtual Power Plant (VPP);
- the RMCU is the Aggregator entity in charge of monitoring power consumptions and actuating commands on the electric loads directly connected to it (e.g., TC 2.1.1 the Heat Pump);
- the KPI Visualization System represents the 5G-Solutions KPI Visualization System.

It is possible to divide the set of communications in five different parts: “5G Network Initialization”, “Starting experiment”, “Measurements Loop”, “Computation of Power Setpoint” and “Termination of the Experiment”.

In the first part, the Experimenter sends to the 5G EVE Facility the complete specifications of the Vertical Service, as well as VNF and NSD, and suitable blueprints, to be loaded for the experiment and the specific parameters (*Service Specification Template*). These messages are sent just once and not every time the experiment starts.

The Experimenter sends also a *Start Experiment* message every time it wants to start the experiment to the Master Control Agent to actually start the experiment. The Master Control Agent will then activate the over-mentioned Service Specs. Templates with the *Service order* message and notifies the KPI Visualization System that the experiment is starting.

In the Measurement Loop, which by current regulations of the TSO should be done every 4 seconds, all the RMCU belonging to the same VPP should send, via 5G communications, the measurements of their loads to the RTU, that in turn sends these measurements to the Master Control Agent. These measurements could be sent also by the Master Control Agent to the 5G-Solutions Visualization System in order to be shown.

In the Computation of Power Setpoint phase the Aggregator receives to its RTU a Dispatching Order (BDE) from the TSO. The RTU sends then a message to the Master Control Agent that is in charge of computing, in a distributed way, the active demand product from the loads present in the VPP. In order to do so, it sends an *Initialization* message to its Local Control Agents via 5G communications. After they receive such a message, they collect the current power measurements from their related RMCUs and start the actual computation. This computation is done by iterations: after a first computation phase of the Local Control Agents, they send back a partial result to the Master Control Agent that starts some computation and gives back a feedback to the Local Control Agents that again starts a second computation phase and so on. All the exchanged messages rely on 5G ultra-reliable low-latency communication in order to reduce as much as possible the communication delay and in order to guarantee the arrival of these messages. After the optimal solution is found (after some iterations between the Master Control Agent and the Local Control Agents) the Master Control Agent sends the computed *Power Setpoints* to the RTU, that in turn sends the *Dispatching Actions* to the relevant RMCUs, as indicated by the *Power Setpoints* message, via 5G communications. At the end the Master Control Agent sends information on the just finished phase (e.g., computing time, network time, etc.) to the KPI Visualization System.

At the end of the Experiment, the Experimenter sends to the Master Control Agent a *Stop Experiment* message. The Master Control Agent terminates all its pending jobs and notifies the termination to the KPI Visualization System.

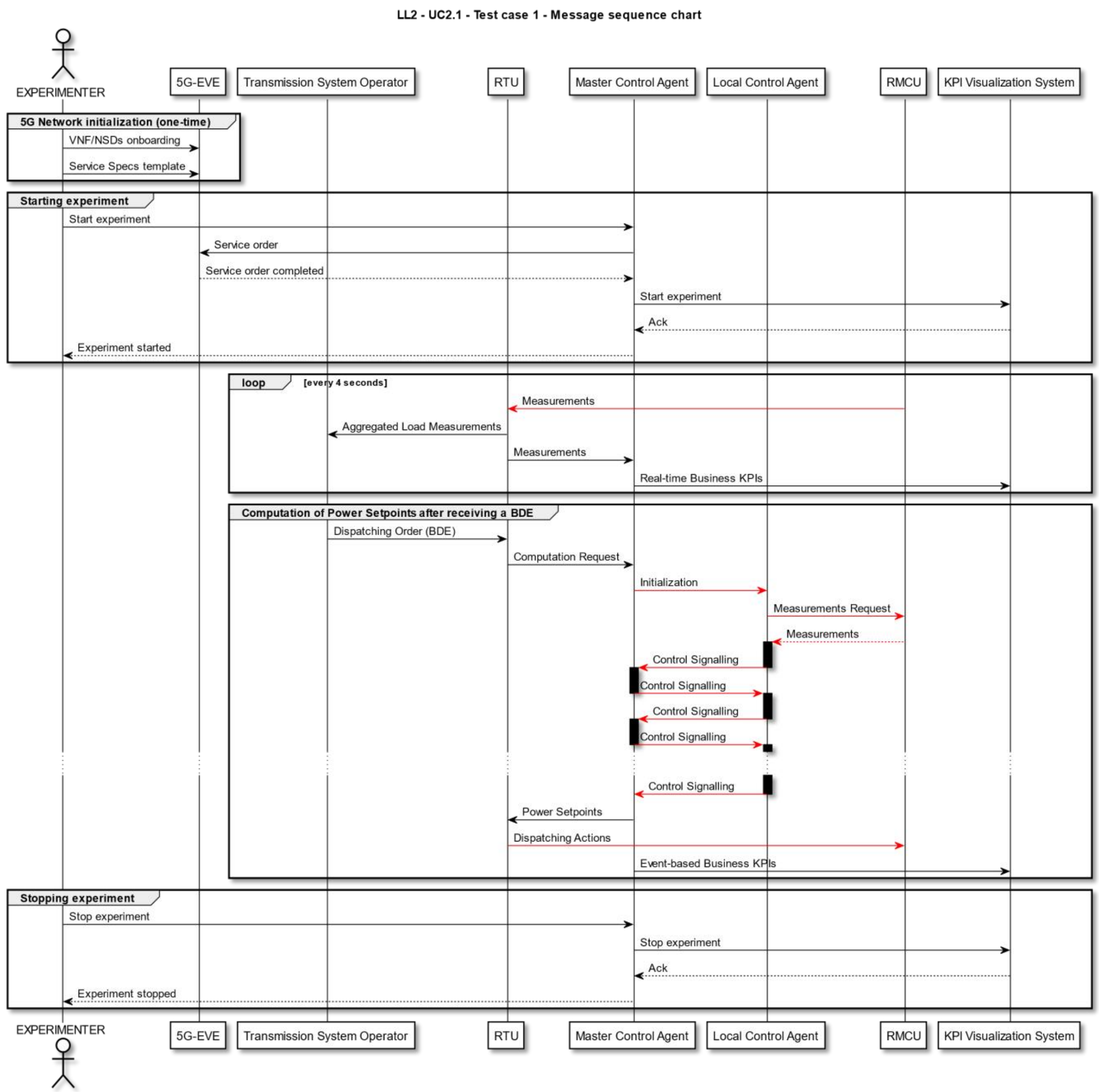

Figure 30 UC2.1 – Message Sequence Chart for TC 2.1.1

TC 2.1.2

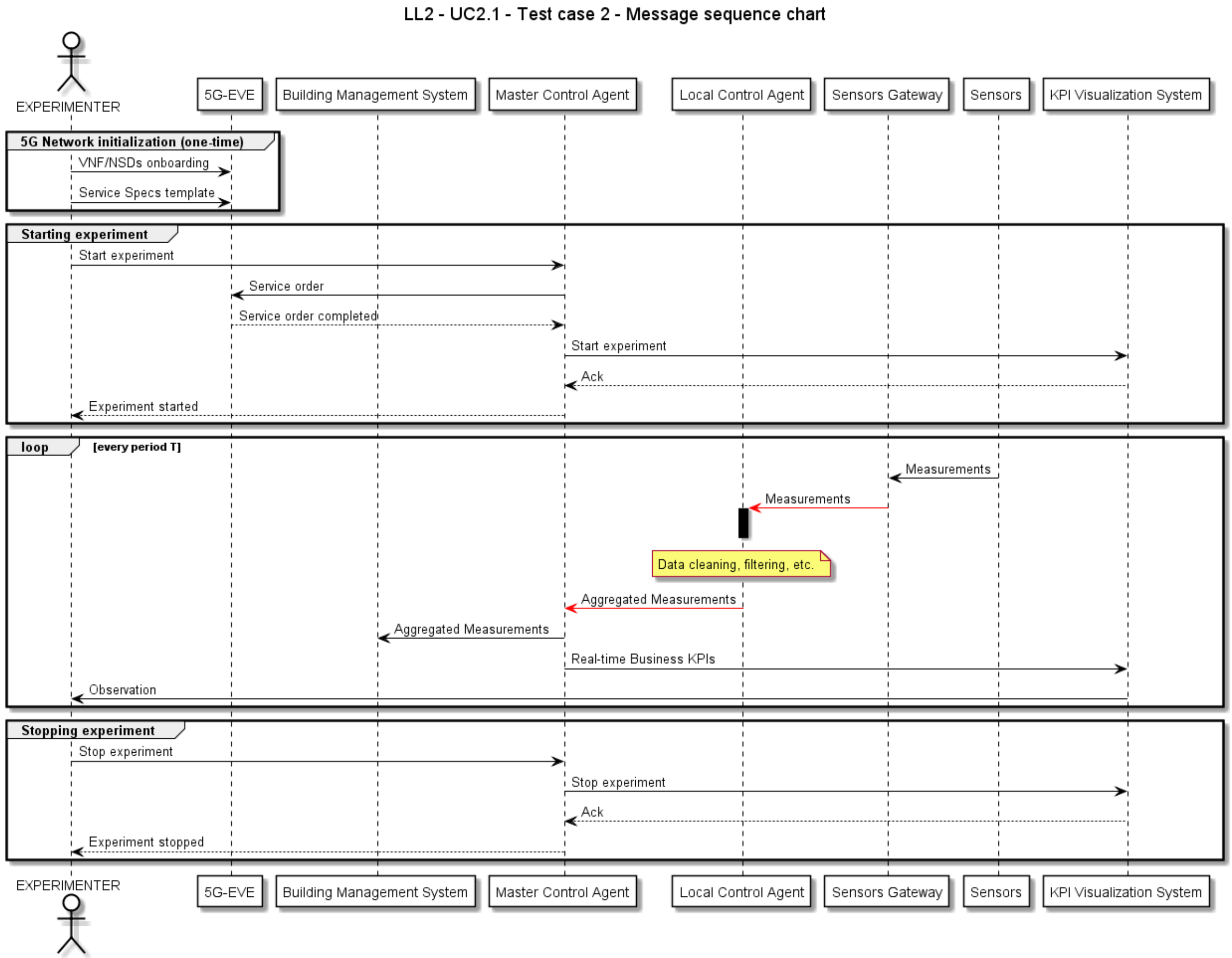

Figure 31 UC2.1 – Message Sequence Chart for TC 2.1.2

The sequence diagram depicted in Figure 31 represents the messages exchanged for the Test Case 2.1.2, considering the specific architecture for this Test Case that includes a subset of the building blocks belonging to the UC 2.1 architecture. All the arrows in the figure represent information flows and not API calls.

For TC 2.1.2 it is possible to identify the following parties:

- the Experimenter represented by the Use Case owner (IREN);
- the 5G EVE block, that represents the 5G infrastructure offered by the 5G EVE platform in the Italian Site located in Turin;
- the Building Management System (BMS), that is the Aggregator Unit in charge of managing the heaters valves in order to offer a desired comfort level;
- the Master Control Agent, that is the Control Service Provider (CSP) backend that is in charge of communicating with the BRS and of managing the Local Control Agents;
- the Local Control Agent, that is the CSP entity in charge of collecting, filtering and cleaning measurements data coming from the Sensors Gateways
- the Sensors Gateway, that is the Aggregator entity in charge of monitoring sensors and collecting data from them;

- the Sensors, that are the actual measurement units, in charge of collecting comfort/power measurements from the field
- the KPI Visualization System represents the 5G-Solutions KPI Visualization System

In this sequence diagram it is possible to identify four sets of messages: "5G Network Initialization", "Starting experiment", "Measurement loop" and "Stopping experiment".

In the first part, the Experimenter sends to the 5G EVE network the specifications of VNF and NSDs to be loaded for the experiment and the specific parameters (*Service Spec. Template*). These messages are sent just once and not every time the experiment starts.

The Experimenter sends also a *Start Experiment* message every time it wants to start the experiment to the Master Control Agent to actually start the experiment. The Master Control Agent will then activate the over-mentioned Service Specs. Templates with the *Service order* message and notifies the KPI Visualization System that the experiment is starting.

In the Measurement loop, the sensors send their data to the Sensors Gateway that in turn forwards them to its Local Control Agent (via 5G communication). The Local Control Agent, then, makes some small computation on data (like data cleaning, filtering, etc.) and then forwards the aggregated measurements to the Master Control Agent, again via 5G communication. These Aggregated Measurements are made available also to the Building Management System/Remote Terminal Unit (RTU) if needed. All the data are also sent to the 5G-SOLUTIONS KPI Visualization System in order to be displayed to the Experimenter.

In the last messages group the Experimenter sends a Stop Experiment message to the Master Control Agent that in turns stops the 5G-Solutions KPI Visualization System and notify the Experimenter that the experiment is successfully finished.

TC 2.1.3

The sequence diagram depicted in Figure 32 represents the message exchanges between the different components of the architecture of the UC 2.1. For TC 2.1.3:

- the **Experimenter** is represented by the Use Case owner (IREN);
- the **5G EVE** block represents the 5G infrastructure offered by the 5G EVE Turin Test Site;
- the **Transmission System Operator (TSO)** is the party in charge of sending Dispatching Orders (BDE) coming from the Energy Market to the Aggregator and to check that the BDE is properly actuated;
- the **Remote controller** is a (virtualizable/dockerizable) software module in charge of applying for a reactive disconnection for black-out avoidance in real time exploiting the ultra-low latency communication with the Proof-of-Concept block offered by the 5G facility;
- the **Proof of Concept (PoC)** is a physical (hardware + software) component in charge of energy sensors monitoring and of applying locally the switch/breaker actuations commanded by the Remote controller block;
- the **KPI Visualization System (KPI VS)** is the 5G-Solutions KPI Visualization System

In the message sequence chart depicted in Figure 32, it is possible to distinguish 5 communication phases:

1. **One-time initialization**: it is common to all the test cases. Each test case must be setup providing the target sites (the Italian Site of 5G EVE Facility for UC 2.1) with proper VNF/NSD configuration and the related service specification;
2. **Starting experiment**: this segment deals with the possibility, for any experimenter, to start a new experiment, informing both the use case related components (e.g., the Remote controller), as well as the project related components (the CDSO). This communication block is common to all the test cases, but the elements involved can vary for test case to test case;

3. **Running experiment**: this segment is test case specific. It deals with the needed communications to correctly and successfully run an instance of the created experiment. During this phase it can be possible, at run time, to monitor the business KPIs.
4. **Stopping experiment**: this segment is common to all the test cases. It deals with the needed communications to stop the experiment informing both the use case related components (e.g., the Remote controller), as well as the project related components (the CDSO).
5. **Post experiment**: this segment is common to all the test cases. During this phase it can be possible to get the 5G Network KPIs from the selected site facility, namely 5G EVE Facility.

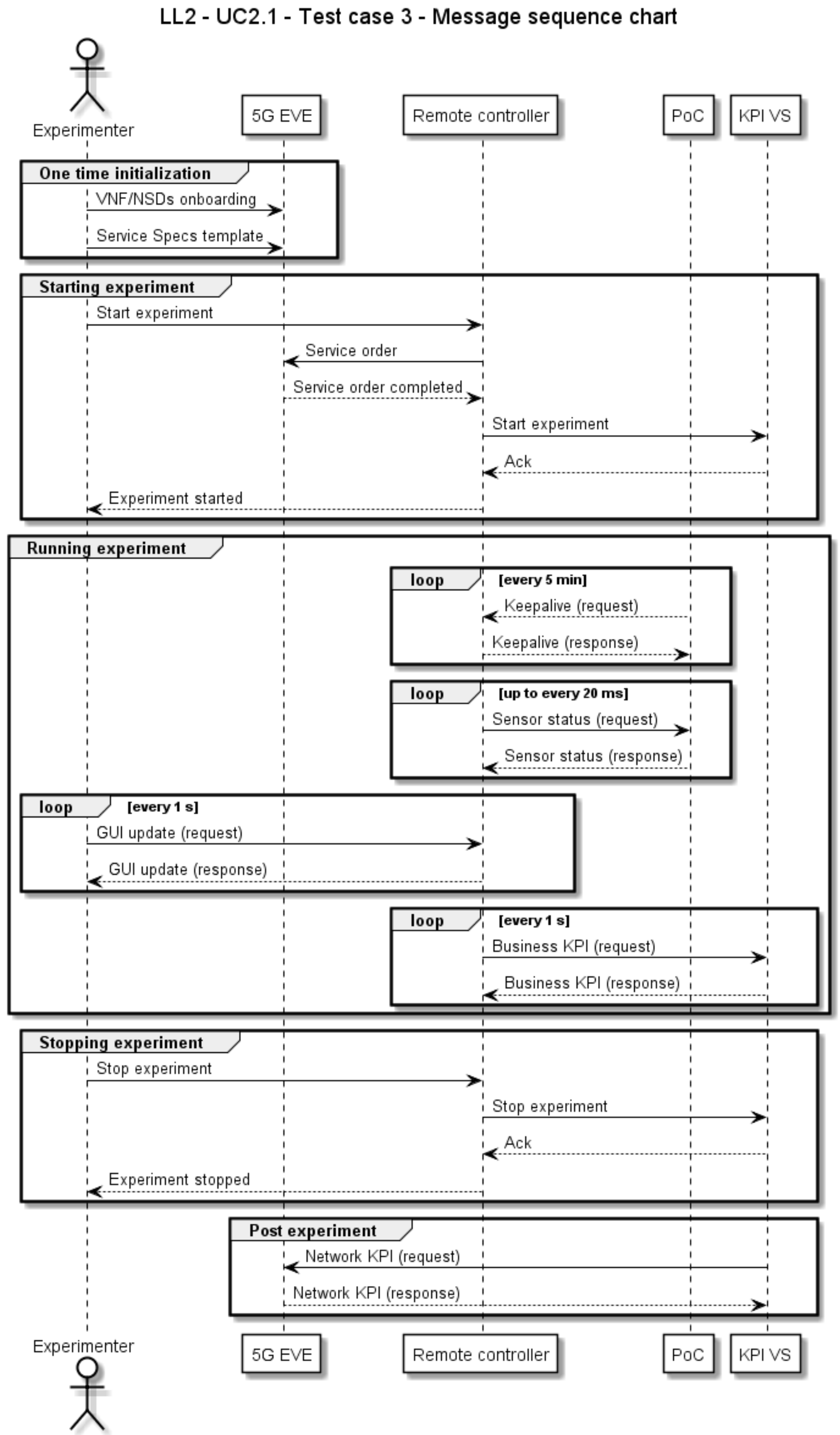

Figure 32 UC2.1 – Message Sequence Chart for TC 2.1.3

5.2.1.4 *Collaboration with the testbeds and deployment*

The collaboration with the testbed hosted by the ICT17 5G EVE Platform is active. The coverage of the test area for running all test cases (TC 2.1.1, TC 2.1.2 and TC 2.1.3, including a pre-trial test case 2.1.0) has been confirmed by the Italian Site Manager (TIM). The covered area for all test cases in UC2.1 includes a building belonging to the Municipality of Turin located in via Francesco De Sanctis 12 as showed in the Figure 33.

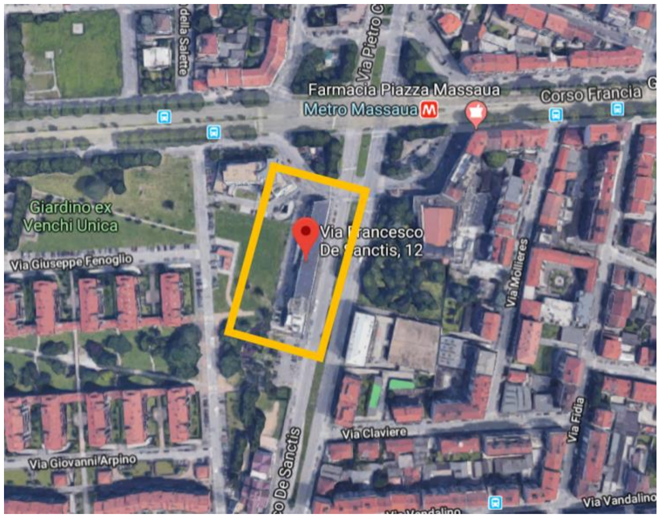

Figure 33: UC2.1 – Area of interest for trials

The main roles for the UC2.1 will be named and played as follows:

- 5G-Solutions Use Case responsible – IREN
- 5G-Solutions VNF producer – Ares2t
- 5G-Solutions Use Case developer – Ares2t

The Site Manager for UC2.1 will be TIM.

In Cycle 1, Test Case TC 2.1.3 will be managed in line with the Experiment Flow Activities proposed by ICT17 project 5G EVE. The aim of the Experiment Flow Activities is the execution of test cases in the indicated area of interest, the test, validation and demonstration of each test case in real conditions, and the collection, validation and report of relevant KPIs, including network and business KPIs. The activities are organized in four groups:

1. Experiment Design – the experiment is conceived and evaluated in terms of feasibility by the 5G-Solutions Use Case responsible and 5G-Solutions Use Case developer; necessary VNF package is on-boarded by 5G-Solutions VNF producer supported by the Site Manager; the experiment is fully specified by G-Solutions Use Case developer that provides the Vertical Service definition and, accordingly, the Experiment definition;
2. Experiment Preparation – the experiment is customized by the 5G-Solutions Use Case responsible according to different network scenarios of interest from the operation and business point of view; the experiment is scheduled by 5G-Solutions Use Case responsible in accordance with the Site Manager, who manages the experiment environment with respect to customization and scheduling;
3. Experiment Execution – the experiment is instantiated and executed under the supervision of the 5G-Solutions Use Case responsible; measurements of network and business KPIs of interest are collected;
4. Experiment Results Analysis – the results from the experiment, including the experiment measurements, are analyzed and evaluated by the 5G-Solutions Use Case responsible.

Each group of Activities involves one or more actors according to the above-mentioned roles. These actors will play their role trough the 5G EVE Portal via web access. In UC2.1, the actors will be IREN and Ares2t, supported by TIM as Site Manager in steps 1 and 2.

Currently, all test cases in UC 2.1 selected for Cycle 1 are in the *Experiment Design* phase, according the Experiment Flow Activities and the Terms and Conditions issued by the ICT17 project 5G EVE. The complete integration process will be described in deliverable D2.1 “Setup and operation of 5G infrastructure”.

5.2.1.5 *Trials planning*

Trials planning for Cycle 1 concerns test case 2.1.3. The plan has been discussed by Use Case responsible (IREN) and the technological partners involved in UC2.1, namely Ares2t (as VNF producer and Use Case developer) and TIM as Site Manager of the Italian Site in 5G EVE Facility. The plan is the following one:

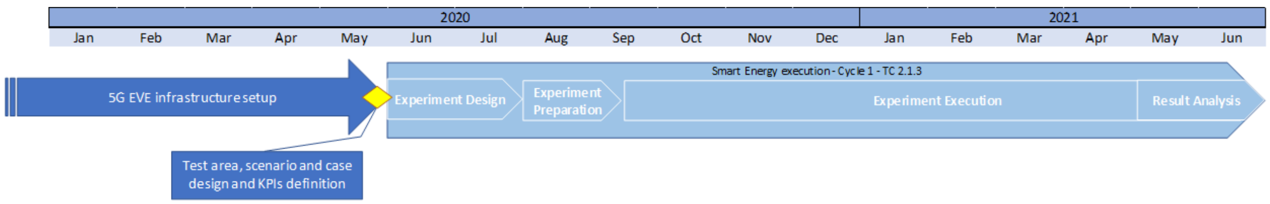

Figure 34: TC2.1.3 – Trial plan

5.2.1.6 *Planned KPIs to be tested*

TC 2.1.3 aims at validating the complete end-to-end communication between the 5G mobile device and the PoC as described in the previous section. The Vertical Service KPI is the *Disconnection Time* summarizing four different indicators in the end-to-end chain of Local Controller's modules. The Network KPIs are network *reliability*, *availability*, and *latency* as well as *user data rate downlink* and *uplink*, in critical context scenarios like the one with delay, potentially affecting the reaction in the control-based management procedure. Reference measurement will impact on analogous test cases in Cycle 2 and Cycle 3 in presence of an actual energy load.

5.2.1.7 *Test cases*

Table 18: UC2.1 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC2.1-PRE	Pre-trial unit and integration test	N-SC	Default scenario and simple network configuration to test connectivity and preliminary integration	Preliminary communication and setup test
UC2.1-SC1	Heat pump and comfort devices monitoring and integration in the energy management system	U-SC, N-SC	Electrical monitoring and/or comfort monitoring devices integration in the energy management system	Evaluate the pros/cons of a 5G communication (compared to 4G) for reliability, flexibility and speed/latency when pushing consumptions data to the BMS and/or RTU Supervision platform. Post fiscal electrical meters could be installed on the main electrical loads of the building (heat pump, Lighting, elevators….). Comfort monitoring sensors could have a local wireless communication to

				a concentrator, with 5G embedded.
UC2.1-SC2	Reactive load disconnection for black-out avoidance	U-SC, N-SC	Reactive load disconnection for black-out avoidance	Compare the 4G against 5G performance in case of fast load disconnection

Table 19: UC2.1 Test Areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC2.1-TA1	E2E 5G communication between 5G EVE facility and mobile device - Test	Unit, Component Test	End to end communication will be tested in the Italian Site of the facility 5G EVE. A 5G mobile device equipped with suitable SIM card will be used to verify the connection with the MEC server located in the facility	To test the 5G communication infrastructure from 5G EVE is working properly on the pilot area
UC2.1-TA2	Main electrical load (heat pump and other energy loads) test area preparation	Unit, Component Test	Heat Pump control and measurement integration with 5G infrastructure (modem/SIM integration in UPMC and/or directly in the PLC/metering system); check the communication with Aggregator RTU (or Building Management System) to send dispatching order main loads (e.g., existing chillers, lighting, etc.) measurement integration with 5G infrastructure (modem/SIM integration in UPMC and/or directly in the metering system); check the communication with Aggregator RTU (or Building Management System)	Test the integration of systems and their functionalities
UC2.1-TA3	Comfort or other sensors integration	Unit, Component Test	Sensors integration with 5G infrastructure (modem/SIM integration in UPMC and/or directly in the metering system); check the communication with Aggregator RTU (or Building Management System)	Test the integration of systems and their functionalities
UC2.1-TA4	Dispatching Market and Local BMS	Integration Test	Simulate integration in a VPP by sending dispatching	Test the integration of systems and their

	Optimizer integration simulation area		order to heat pump and see how it will manage the load modification	functionalities

Table 20: UC2.1 TCs Matrix

	TC01	TC02	TC03	TC04
Test Areas	UC2.1-TA1	UC2.1-TA2	UC2.1-TA3	UC2.1-TA4
Target Vertical KPIs - Primary & Secondary				
Reliability	1st	1st	1st	1st
Latency	2nd	2nd	2nd	2nd
Area traffic capacity	2nd	2nd	2nd	2nd
Successful data pushing rate (pushing measurements and receiving dispatching orders		1st	1st	1st
Indoor comfort evaluation KPI during loads management actuation (temp, RH…others)		1st	1st	1st
Unbalancing comparison to dispatching order (due to communication problems)				1st
Scenario ID				
UC2.1-PRE	2.1.0			
UC2.1-SC1		2.1.1.1	2.1.2	2.1.1.2
UC2.1-SC2				2.1.3

5.2.2 UC2.2: Electrical Vehicle (EV) Smart Charging

5.2.2.1 *UC test objective and design*

In Cycle 1, two kinds of test cases are defined for UC2.2: one is for ICT standalone LL software components and the other for pre-trial 5G connectivity in the Test Sites for the relevant hardware and software components. Test Site will be covered by the Italian Site of the ICT17 5G EVE Platform. Pre-trial 5G connectivity tests aim at determining on-field network KPI values related to network coverage, reliability and latency. Majority of individual tests can be performed in the Test Site without the need of integration among software and hardware components of different partners working in the LL, while integration tests require to run one experiment involving different components of the architecture that will be presented in the following Section 5.2.2.3.

The **reference scenario** for test cases planned for execution in Cycle 1 is the pre-trial and integration test one. **Test area** of interest in Cycle 1 is the dispatching market integration simulation area for test case 2.2.3, referring to the simulation of integration in a Virtual Power Plant (VPP) by sending dispatching order to charging points to see how it will manage the load modification (also considering final EV user interface).

Three test cases have been identified to completely test and validate the Use Case:

- **TC2.2.1**: **EV charging session ON/OFF** to test preliminary charging session status and command tests as well as validating Network KPIs for test area preparation to support the following test cases.
- **TC2.2.2**: **Smart EV charging session** to test Vertical Service KPIs in terms of service reliability, flexibility and speed/latency when charging data are transmitted from the field to back-end system and modulation orders can be received for flexibility purposes in simulated smart charging sessions.
- **TC2.2.3**: **Distributed smart charging in 5G environment** for pre-trial integration purposes with no active loads (Electric Vehicles) and, accordingly, no real charging data from the field.

This use case performed cycle 1 trials.

5.2.2.2 *Test planning*

The reference GANTT for UC 2.2 is depicted in Figure 35. For each macro activity, the related tasks are indicated as well as the period of activity and due deliverables. Six macro activities over nine will be active during Cycle 1. During Cycle 1, the test case TC 2.2.3 will be designed, prepared, executed and evaluated in terms of results and relevant KPIs in the 5G EVE Facility. Moreover, in Cycle 1 a specific algorithm to enable smart charging services will be designed, simulated and validated to support test cases to be executed in Cycle 2 and Cycle 3. Within the end of Cycle 1 we expect to design, simulate and analyse an ad-hoc control algorithm for UC 2.2. The algorithm design and refinement will require the knowledge of (real) operational condition, so in parallel to the development of the algorithm, the result of pre-trial test case will be taken into account in order to identify the operating conditions in terms of 5G network KPIs. At the end of Cycle 1 we expect to build prototype stand-alone software modules that implement the building blocks of the architecture needed for the execution of the over-mentioned algorithm.

The stand-alone software modules will be initially tested at lab scale and then gradually integrated with the 5G EVE Turin facility and KPI visualization system. The specific test case TC 2.2.3 will be performed in order to test the performance of the control algorithm when using 5G communications, before further integrating it with the charging infrastructure in the next project cycles.

Experimental results from execution of pre-trial TC 2.2.3 and scientific results from research activities carried out during Cycle 1 will lead test case design for Cycle 2.

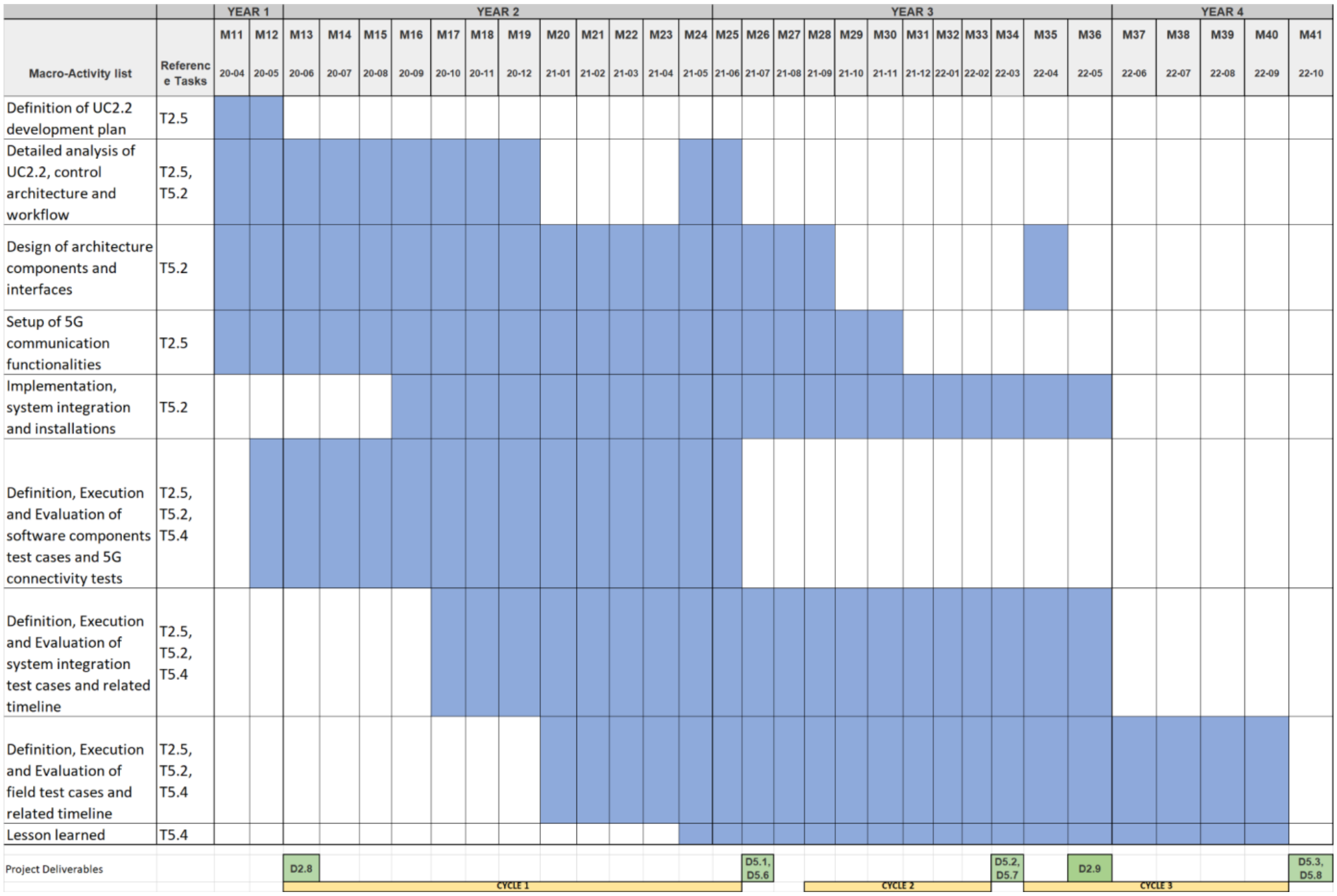

Figure 35 UC2.2 – GANTT

5.2.2.3 *UC architecture and Information flow*

5.2.2.3.1 UC architecture

UC 2.2 is devoted to test and validate the effectiveness of the 5G technology in speeding-up the evolution of new energy services that can be exposed both to the industry and public consumers' landscape. The fast-growing of electric vehicles market introduces new challenges in the management of energy sources to ensure at the same time charging performances, the profitability of the Charging Point Operator and security in terms of grid operations. The 5G technologies, in this scenario, can provide significant improvements of computational capabilities exploiting the property of Ultra-Reliable Low-Latency Communication (URLLC) that allows to demand and distribute computations of complex control algorithms to the devices that want to benefit of the smart charging service and at the same time allows to breakdown the management of the electrical vehicles' overall infrastructure, increasing the competitiveness. As in UC2.1, in the proposed architecture depicted in Figure 36 are identified different layers of competence:

- Transmission System Operator (TSO) Layer
- Charging Point Operator (CPO) Layer
- Control Service Provider (CSP) Layer

The overall control architecture is supported by the presence of the 5G EVE Facility guaranteeing suitable coverage in the area of interest for UC 2.2.

The architecture is composed of the following operational blocks and entities:

- The 5G EVE block, that represents the 5G infrastructure offered by the 5G EVE Turin Test Site;

- The Transmission System Operator, which is an external part, has the capabilities to send dispatching orders that can modify the operational conditions. The presence or not of the dispatching order does not influence the principle of the lower layers;
- The Charging Point Operator boots up the charging sessions and activates the sequence of actions needed to compute the charging schedules. The CPO Layer contains two main elements:
    - the E-Mobility back-end, that has a central role in the communication between the different layers. In this block there are the interfaces and communication protocols needed to the interaction between the TSO, Load Area and CSP. The E-mobility back-end is in charge of:
        - handle new charging session and notify them to the CSP;
        - collect measurements from the Load Area and forward them to the CSP for the computation of the charging scheduling;
        - accept and put into effect the charging session schedules coming from the CSP;
    - The Load Area hosts the controllable nodes such as Charging Station and Electric Vehicles. Charging Station is the CPO hardware capable of charging an Electric Vehicle according to IEC 61851 standards. The Load Area is in charge of:
        - get the charging schedules coming from the E-Mobility Platform;
        - actuate the charging schedules on the electric vehicles;
        - provide to the E-Mobility Platform the power measurements.
- The Control Service Provider offers the service of controlling the flexible loads in a distributed fashion. The CSP layer is composed by two different blocks, the CSP Back-End, that contains what in the architecture is called Master Control Agent and the distributed components, identified below by Local Control Agents.
    - Master Control Agent has many roles it is in charge of managing and coordinating Local Control Agents, it executes part of the scheduling computation (together with the Local Controllers), but it also works as interface with the CPO Layer and KPI Visualization System, in details:
        - the Master Control Agent communicates to the E-Mobility Platform in order to:
            - notify the starting of new Charging Sessions;
            - collect and manage the electrical measurements and operational conditions;
            - send Scheduling for the Charging Stations;
        - the Master Control Agent interacts with the KPI Visualization System in order to allow the visualization of both business and technological KPIs; the Master Control Agent interacts with the Local Control Agents in order to manage the distributed computational phase, in detail:
            - notifies the charging request, so enables the Local Control Agents to take part to the computation
            - sends the information needed for the computation, in this architecture identified by the arrow labelled as Measurements;
            - continuously interacts with them exchanging control signaling during the scheduling computation loop;
        - the Master Control Agent, as mentioned before, contributes also in the computation of the charging schedule;
        - Local Control Agents are in charge of computing the Scheduling in a distributed way. A Local Control Agent communicates only with the Master Control Agent and it is designed to: receive charging requests and measurements from the Master Control Agent;
        - have computational capability in order to compute the scheduling;

The Local Control Agents interact with the Master Control Agent through what in the architecture is called Control Signaling. This exchange of information is needed to the distributed computation of the Scheduling. When a user, identified by the Local Control Agent hosted in the 5G mobile device (e.g., a commercial smartphone), asks for a new charging session, the request is sent to the Master Control Agent, which notifies the request to the E-Mobility Platform; this request triggers a set of communications between the Local Control Agents and the Master Control Agent for the acquisition of needed control information and for initialization of a set of computations. The computation phase requires a lot of fast and reliable communications between Master and Local agents; at the end of the computation the schedule is sent back to the E-Mobility Platform that will actuate the power setpoints. In all the procedures, the relevant KPIs are sent to the KPI Visualization System. Similar actions are repeated iteratively during all the charging sessions to control and adjust the charging schedule to the eventually new boundary conditions given by the TSO or in general to compensate for the inevitable uncertainties in the system.

In Cycle 1 we plan to simulate in stand-alone mode and then in integrated mode with the 5G infrastructure (TC2.2.3) and some of the prototypal building blocks of the proposed high-level architecture for UC 2.2. From this perspective, the interested blocks are the Master Control Agent and the Local Control Agents. At the end of Cycle 1, we expect to produce, even if in a preliminary version, an implementation of these two building blocks sophisticated enough to be able to support the execution of the full UC in the subsequent project trial cycles.

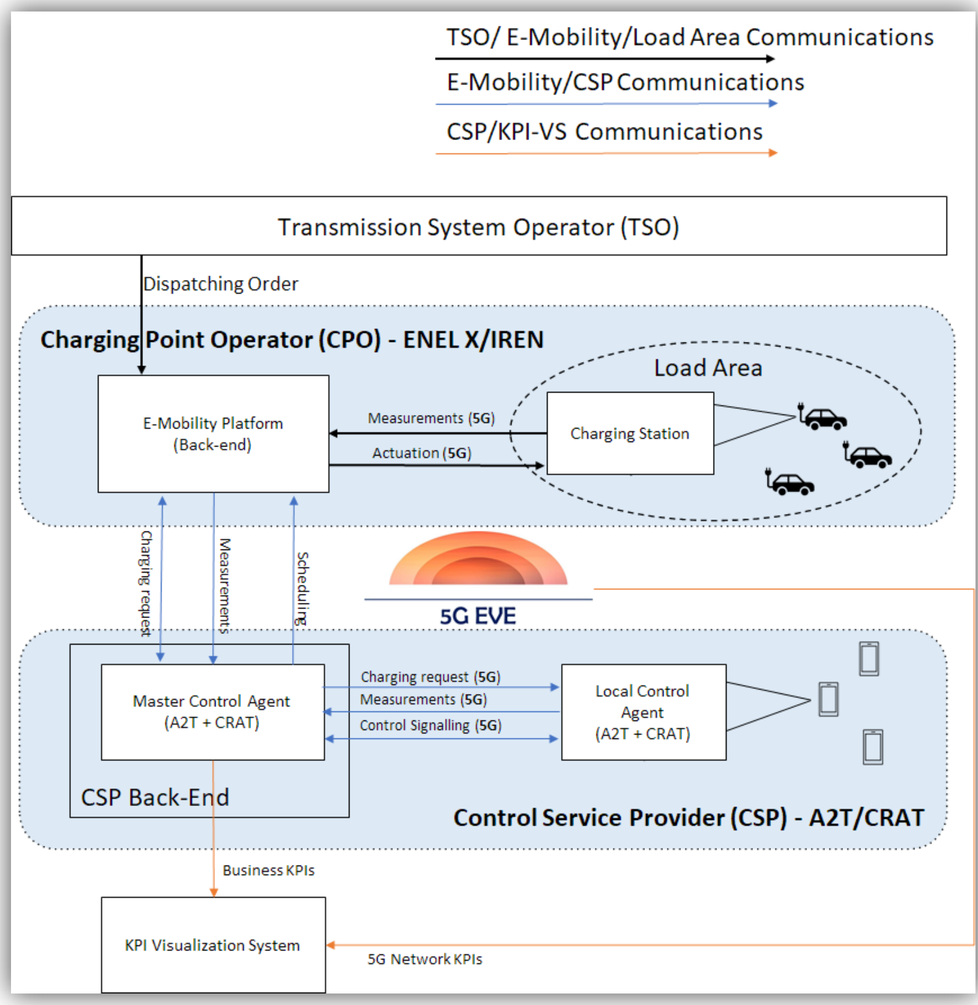

Figure 36 UC2.2 – Reference architecture

5.2.2.3.2 *Information sequence diagram*

The message sequence chart depicted in Figure 37 represents the message exchanges between the components belonging to the UC2.2 architecture. The following components are considered:

- the Experimenter represents UC2.2 owner (IREN)
- the 5G EVE block represents the 5G infrastructure offered by the 5G EVE Turin Test Site
- the Transmission System Operator is in charge of sending Dispatching Orders for the Load Areas belonging to the Charging Point Operator (CPO) in case of network imbalances
- the E-Mobility Platform is a CPO platform that manages all the Charging Stations of the CPO
- the Mobile Control Agent is the Control Service Provider (CSP) backend and communicates to the E-Mobility Platform to send Scheduling for Charging Station and to be notified of new Charging Sessions (*Charging Requests*); moreover, it is in charge of managing the Local Control Agents
- the Local Control Agent belongs to the CSP and is in charge of computing the Scheduling in a distributed way with the other Local Control Agents and with the Master Control Agent
- the Charging Station is the CPO hardware capable of charging an Electric Vehicle according to IEC 61851 standards
- the KPI Visualization System is represented by the 5G-Solutions Visualization System

For UC2.2 it is possible to identify four different sets of messages: 5G Network Initialization, User Charging Request and TSO Dispatching Order, Measurements and Scheduling loop and Termination of the Experiment.

In the first phase, 5G EVE infrastructure is initialized with the *una-tantum* messages for VNF/NSDs onboarding and Service Spec. Templates. These messages are used to setup the 5G EVE platform for the UC2.2 experiments. At the start of an Experiment, the Experimenter sends also the *Start Experiment* message to the Master Control Agent to activate it, and in turns it activates the over-mentioned VNF/NSDs previously sent by the Experimenter.

In the second set of messages, upon a TSO Dispatching Order to the E-Mobility Platform, the latter forwards the message to the Master Control Agent, in order to be considered in the next scheduling computations. Upon a new *Charging Request* from the End-User, the Local Control Agent forwards it to the Master Control Agent via 5G communications and the Master Control Agent forwards it to the E-Mobility Platform. The E-Mobility Platform, then sends the *Actuation* command (via 5G communications) to the Charging Station in order to start the Electric Vehicle charging. At the end, the E-Mobility Platform sends back to the Master Control Agent a *Notification* of the newly created charging session it should consider for the next scheduling.

In the Loop phase, the E-Mobility Platform receives the measurements from all its Charging Stations (via 5G communications) and forwards them to the Master Control Agent that in turn sends these measurements also to all the related Local Control Agents (via 5G communications). These measurements could be sent also to the KPI Visualization System by the Master Control Agent to be visualized. When the E-Mobility Platform requests the computation of a new scheduling for the next time period to the Master Control Agent, it sends an *Initialization* message to the Local Control Agents (via 5G communications) in order to let the Local Control Agent start computing a new scheduling given the current set of measurements and charging sessions. After a first computation phase, the Local Control Agents sends back to the Master Control Agent a partial result; then the Master Control Agent makes some computation and sends back to the Local Control Agent a feedback; then the Local Control Agents start again a second phase of computation and so on, until they reach convergence. All these communications are sent via 5G network. At the end, the Master Control Agent sends the computed *Scheduling* to the E-Mobility Platform that forwards to its Charging Stations the proper *Actuation* commands according to the computed scheduling via 5G communications. The Master Control Agent then could send information on what has happened in the Loop phase (e.g. computing time, network time) to the KPI Visualization System.

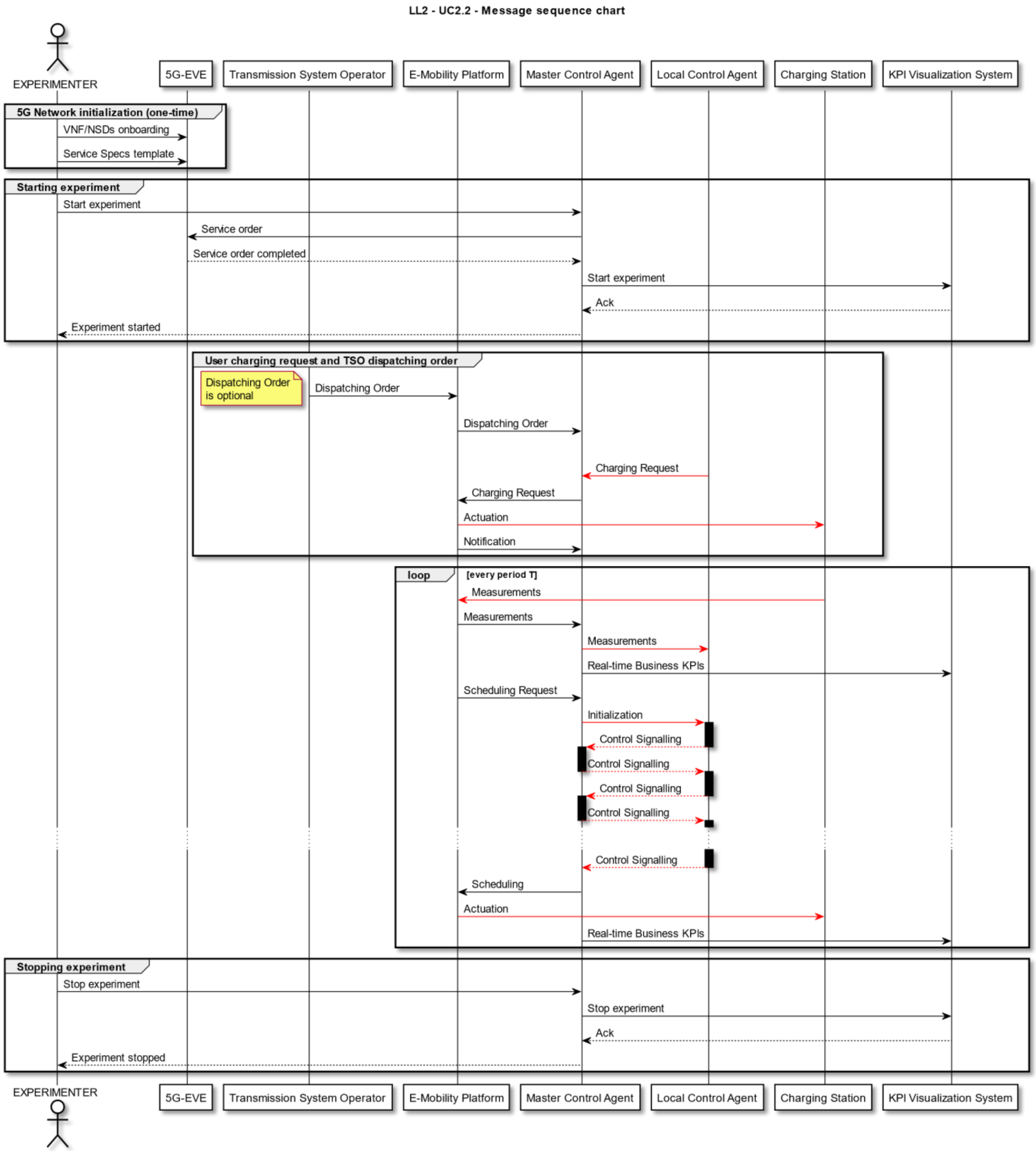

Figure 37: UC2.2 – Message Sequence Chart

5.2.2.4 *Collaboration with the testbeds and deployment*

The collaboration with the testbed hosted by the ICT17 5G EVE Platform is active. The coverage of the test area for running all test cases (TC 2.2.1 and, TC 2.2.2, including pre-trial test case 2.2.3) has been confirmed by the Italian Site Manager (TIM). The covered area for all test cases in UC2.2 include a parking area at IREN's premises in the yellow polygon as showed in the Figure 38.

Figure 38: UC2.2 – Area of interest for trials

The main roles for the UC 2.2 will be named and played as follows, namely:

- 5G-Solutions Use Case responsible – IREN
- 5G-Solutions VNF producer – Ares2t
- 5G-Solutions Use Case developer partner – Ares2t

In Cycle 1, test case TC 2.2.3 will be managed in line with the Experiment Flow Activities proposed by the ICT-17 project 5G EVE. The aim of the Experiment Flow Activities is the execution of test cases in the indicated area of interest, the test, the validation and the demonstration of each test case in real conditions, and the collection, validation and report of relevant KPIs, including network and business KPIs. The activities are organized in four groups:

1. Experiment Design – the experiment is conceived and evaluated in terms of feasibility by the 5G-Solutions Use Case responsible and 5G-Solutions Use Case developer; necessary VNF package is on-boarded by 5G-Solutions VNF producer supported by the Site Manager; the experiment is fully specified by G-Solutions Use Case developer that provides the Vertical Service definition and, accordingly, the Experiment definition;
2. Experiment Preparation – the experiment is customized by the 5G-Solutions Use Case responsible according to different network scenarios of interest from the operation and business point of view; the experiment is scheduled by 5G-Solutions Use Case responsible in accordance with the Site Manager, who manages the experiment environment with respect to customization and scheduling;
3. Experiment Execution – the experiment is instantiated and executed under the supervision of the 5G-Solutions Use Case responsible; measurements of network and business KPIs of interest are collected;
4. Results Analysis – the results from the experiment, including the experiment measurements, are analysed and evaluated by the 5G-Solutions Use Case responsible.

Each group of Activities involves one or more actors according to the above-mentioned roles. These actors will play their role through the 5G EVE Portal via web access. In UC2.2, the actors will be IREN and Ares2t, supported by Enel X for charging station provisioning and by TIM as Site Manager in steps 1 and 2.

Currently, the test case in UC2.2 selected for Cycle 1 is in the Experiment Design phase, according the Experiment Flow Activities and the Terms and Conditions issued by the ICT17 project 5G EVE. The complete integration process will be described in deliverable D2.1 "Setup and operation of 5G infrastructure".

5.2.2.5 *Trials planning*

Trials planning for Cycle 1 concerns Test Case TC 2.2.3. The plan has been discussed by Use Case responsible (IREN) and the technological partners involved in UC2.2, namely Ares2t (as VNF producer and Use Case developer), Enel X for energy equipment, and TIM as Site Manager of the Italian Site in 5G EVE Facility. The plan is the following one:

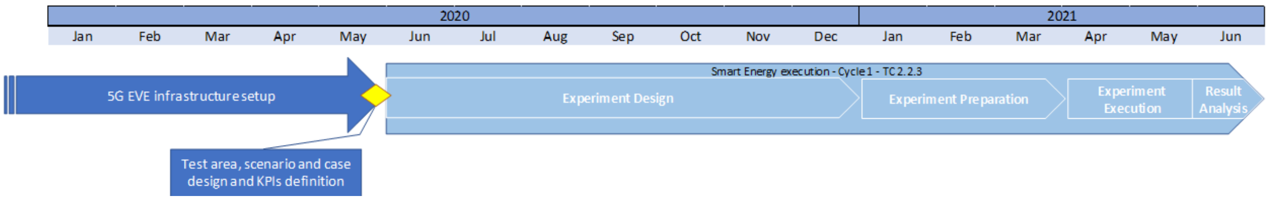

Figure 39: TC 2.2.3 – Trial plan

5.2.2.6 *Planned KPIs to be tested*

The Test Case TC 2.2.3 aims at testing and validating the Vertical Service implementing the distributed smart charging control procedure in 5G environment for pre-trial integration purposes. Therefore, no active load (Electric Vehicle) and no real data are considered. The Vertical Service KPIs include the deviation between the (controlled) target and the (actual) aggregated charging power curve during the test case execution, the State-of-Charge evolution, and most importantly the sampling time to evaluate the effectiveness of the Vertical Service. Network KPIs include network *reliability* and *latency Round Trip Time* in the covered area in different context scenarios (with particular attention to high network traffic) to simulate actual situations impacting on timing and processing capabilities of the control-based management procedures being under developing for Cycle 2. Reference measurements will impact on other test cases (especially TC 2.2.2) in Cycle 2 and Cycle 3 in presence of actual energy load and network traffic.

5.2.2.7 *Test Cases*

Table 21: UC2.2 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC2.2-PRE	Pre-trial unit and integration test	N-SC	Default scenario and simple network configuration to test connectivity and preliminary integration	Preliminary communication and setup test
UC2.2-SC1	EV charging session ON/OFF evaluating TLC communication KPIs	U-SC, N-SC	Preliminary charging session status and command tests	Evaluate the pros/cons of a 5G communication (compared to 4G) for reliability, flexibility and speed/latency when charging data from the field to backend system and receive modulation orders for flexibility purposes.
UC2.2-SC2	Smart charging sessions	U-SC, N-SC	Simulate smart charging session	Evaluate the pros/cons of a 5G communication (compared to 4G) for reliability, flexibility and speed/latency when charging data from the field to backend system and receive modulation orders for flexibility purposes.

Table 22: UC2.2 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC2.2-TA1	E2E 5G communication between 5G EVE facility and mobile device - Test	Unit, Component Test	End to end communication will be tested in the Italian Site of the facility 5G EVE. A 5G mobile device equipped with suitable SIM card will be used to verify the connection with the MEC server located in the facility	To test the 5G communication infrastructure from 5G EVE is working properly on the pilot area
UC2.2-TA2	Charging points test area preparation	Unit, Component Test	Charging points integration with 5G infrastructure (modem/SIM integration); check the communication with backend system	Test the integration of systems and their functionalities
UC2.2-TA3	Dispatching Market integration simulation area	Integration Test	Simulate integration in a VPP by sending dispatching order to charging points and see how it will manage the load modification (also considering final EV user interface)	Test the integration of systems and their functionalities

Table 23: UC2.2 TCs Matrix

	TC01	TC02	TC03
Test Areas	UC2.2-TA1	UC2.2-TA2	UC2.2-TA3
Target Vertical KPIs - Primary & Secondary			
Reliability	1st	1st	1st
Latency	2nd	2nd	2nd
Area traffic capacity	2nd	2nd	2nd
Successful data pushing rate (pushing measurements and receiving dispatching orders		1st	1st
Energy flow, charging sessions and duration during tests		1st	1st
unbalancing comparison to dispatching order (due to communication problems)			1st
Scenario ID			
UC2.2-PRE			2.2.3
UC2.2-SC1		2.2.1	
UC2.2-SC2			2.2.2

5.2.3 UC2.3: Electricity network frequency stability

5.2.3.1 *UC test objective and design*

In Cycle 1, the pre-trial test case TC 2.3.0 is defined for UC2.3 for 5G connectivity in the Test Site for the relevant software components. Test Site will be covered by the Italian Site of the ICT17 5G EVE Platform. Pre-trial 5G connectivity test aims at determining on-field network KPI values related to network coverage, reliability and latency. The most of tests can be performed in the Test Sites without the need of integration among software and hardware components of different partners working in the LL.

The reference scenario for test cases in Cycle 1 is the pre-trial and integration test one. Test area of interest in Cycle 1 is the E2E 5G communication between 5G EVE facility and a mobile device to test the connection to the MEC server hosted in the Italian Site of the ICT17 5G EVE platform for test case 2.3.0.

This use case performed cycle 1 trials.

5.2.3.2 *Test planning*

The reference GANTT for UC 2.3 is depicted in Figure 40. For each macro activity the related tasks are indicated as well as the period of activity and due deliverables. Six macro activities over nine will be active during Cycle 1.

During Cycle 1 the test case TC 2.3.0 will be designed, prepared, executed and evaluated in terms of results and relevant KPIs in the 5G EVE Facility. Moreover, we plan to simulate in standalone mode some of the prototypal building blocks presented in the architecture in Figure 41. In particular we plan to simulate the Master Control Agent together with the Frequency Control Agents. At the end of Cycle 1 we expect to produce a preliminary version of the algorithms for the above-mentioned building blocks, in order to be ready to make tests and to prepare for the integration in Cycle 2.

Experimental results from execution of pre-trial TC 2.3.0 and results from design and research activities, and finally definition of interfaces with the Visualization System together with their preliminary implementation and testing carried out during Cycle 1 will lead to test case design for Cycle 2.

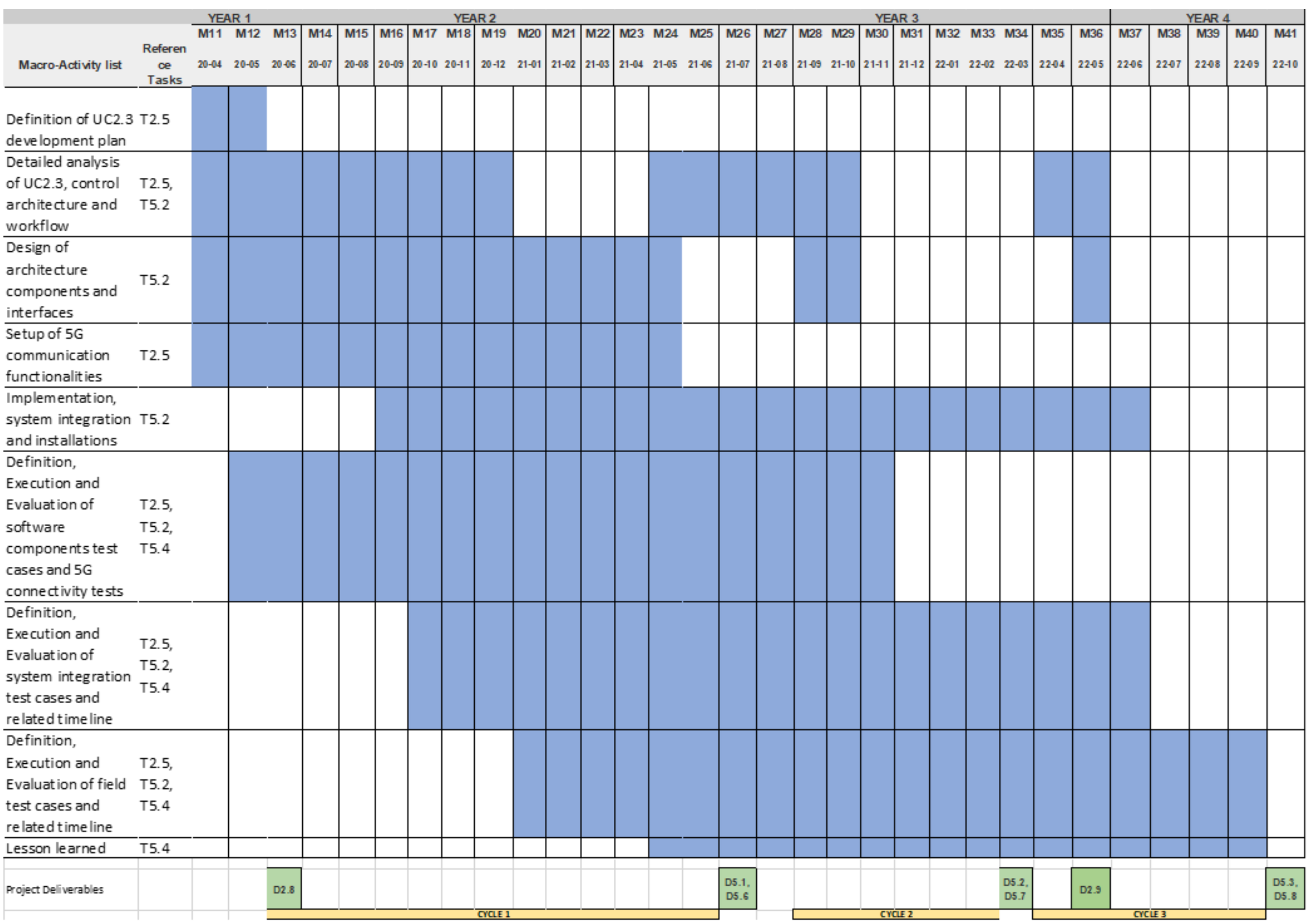

Figure 40: UC2.3 – GANTT

5.2.3.3 *UC architecture and Information flow*

5.2.3.3.1 UC architecture

UC2.3 aims to test and validate the effectiveness of 5G technologies in order to enable frequency regulation services for the electricity network making use of sets of high-power controllable loads such as Electric Vehicles. Such frequency regulation services are traditionally provided by Generation Companies through some frequency control loops applied on their synchronous generators. In such a context, instead, we will enable charging Electric Vehicles to participate in the frequency regulation market thanks to the Ultra-Reliable Low-Latency Communication (URLLC) provided by 5G technologies. In fact, 5G communications are used in order to transmit frequency measures from a Frequency Meter (installed in a Master Charging Station) to all the Slave Charging Stations inside the same Load Area. Such measures have to be transmitted in a very reliable way and with a negligible delay in order for the frequency control to be effective: the cumulative time for communication, computation and actuation must be less than a second. As previous UC 2.1 and UC 2.2, it is possible to divide such an architecture depicted in Figure 41 in three layers:

- Transmission System Operator (TSO) Layer
- Charging Point Operator (CPO) Layer
- Control Service Provider (CSP) Layer

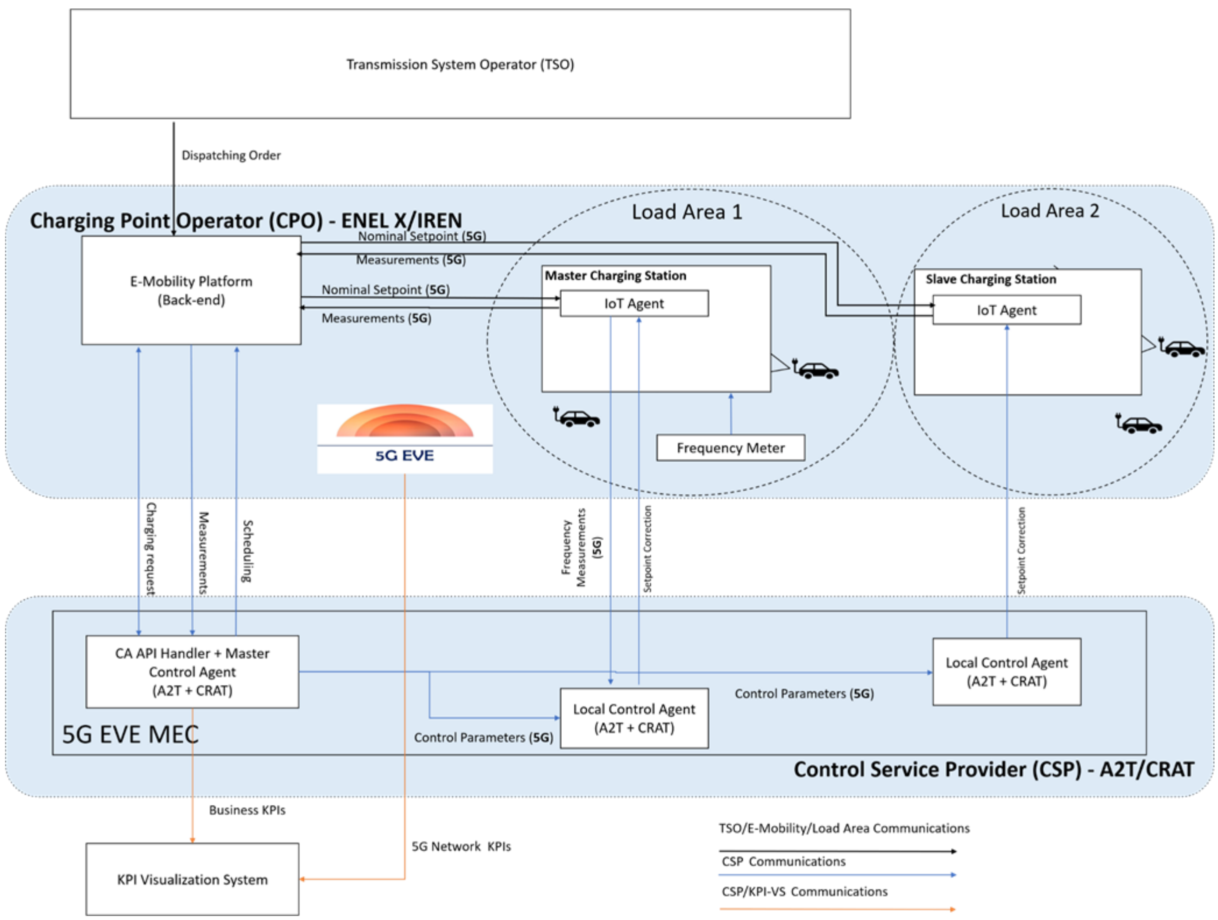

Figure 41 UC2.3 – Reference architecture

The above-mentioned architecture is then composed by the following operational blocks and entities with the following one:

- The 5G EVE block represents the 5G EVE Facility, Italian Site located in the City of Turin.

- The Transmission System Operator (TSO) is an external entity that in this architecture is responsible for sending Dispatching Orders to the E-Mobility Platform in case of electricity network frequency issues.
- In the Charging Point Operator (CPO) layer there are:
    - the E-Mobility Platform, that has the roles of:
        - managing all the Charging Stations (both Master and Slaves) in each Load Area (through proprietary communication protocol)
        - sending Nominal Setpoints and receiving Energy and Frequency Metering from the Charging Stations
        - to communicate with the TSO and to communicate with the Control Service Provider in order to forward the collected Measurements
        - to receive the computed Nominal Scheduling and to be notified about new charging sessions;
    - the Load Area groups a set of controllable loads (i.e. Charging Stations); there are two types of Charging Stations in the Load Areas:
        - the Master Charging Station, that is connected to an external Frequency Meter in order to measure with a high sample rate the electricity network frequency (this measure is communicated to the Local Control Agents, host in the MEC, by the IoT Agent)
        - a number of Slave Charging Stations, that host the IoT Agent, take the set point corrections from the Local Control Agent using 5G communications; The IoT Agents is the interface by which the charging stations communicate with the network connected blocks.;
- The Control Service Provider (CSP) offers control services to the CPO, in order to control its flexible loads:
    - The Master Control Agent, hosted in the MEC, is in charge of computing the Scheduling for charging sessions (in a distributed way, as in UC 2.2, or in a centralized way) given a set of Measurements (given by the E-Mobility Platform) and of notifying the E-Mobility Platform for new charging sessions. The Master Control Agent is also responsible for the computation of the Control Parameters needed for the calculation of the setpoint correction. Moreover, it is in charge of interacting with the 5G-Solutions KPI Visualization System, sending relevant technical and business KPIs.
    - The Local Control Agents, hosted in the MEC, receive the Control Parameters and the frequency measurements, compute the setpoint corrections and send them to the associated charging station (both Master and Slave) using 5G Communications.

In cycle one of UC 2.3 a rationale to enable frequency regulation services will be designed and simulated. The interfaces between the Master Control Agent and the KPI Visualization System will be defined and tested, allowing monitoring of vertical KPIs. Moreover, 5G connectivity tests will be performed in order to be able to monitor the relevant 5G technological KPIs. Such KPIs will be used in order to refine the algorithm and the architecture needed to execute the use case within the hard temporal constraints imposed by the frequency regulation service.

These activities will drive the choice of the hardware components (e.g., the frequency meter), the design and the implementation of test cases planned for Cycle 2 and 3. At the end of cycle one we expect to have a simulation environment to test the rationale behind the frequency regulation service, also taking into account the communication latency of different communication technologies, and a set of detailed specifications for interfacing the Master Control Agent with the KPI Visualization System.

5.2.3.3.2 Information sequence diagram

The message sequence chart depicted in Figure 42 represents the message exchanges between the components belonging to the UC2.3 architecture. All the arrows in the figure represent information flows and not API calls.

It is possible to identify six different set of messages: 5G Network Initialization, Starting Experiment, User Charging Request and TSO Dispatching Order, Measurements and Scheduling loop, a nested Frequency Control loop and Termination of the Experiment.

In the 5G Network Initialization the Experimenter (i.e., the UC2.3 Owner, namely Enel X) prepares the 5G EVE Facility for the experiment located in the Italian Site with suitable network parameters with the one-time messages for VNF/NSDs onboarding and for Service Spec. Template. Then it starts the actual experiment execution with the Start experiment set of messages: The Experimenter triggers the Master Control Agent that in turns activates the above mentioned 5G EVE previously loaded services and starts the 5G-Solutions KPI Visualization System.

In the third group of messages, the Transmission System Operator may trigger the E-Mobility Platform with a Dispatching Order message (e.g., a certain Power-Frequency curve the E-Mobility Platform should guarantee), that in turns forwards the message to the Master Control Agent, which has to be aware of the new Dispatching Order to compute a feasible schedule for the CPO's Charging Stations. After some time, upon a new Charging Request from the End-User to the Master Control Agent, the latter forwards the request to the E-Mobility Platform in order to actually start the power delivery to the End-User's Electric Vehicle, and in turns the E-Mobility Platform notifies the new charging session has started to the Master Control Agents.

In the fourth group of messages, a Local Control Agent collects the frequency measurements from the Frequency meter (passing through the IoT Agent of the Master Charging Station) via 5G communication. These measurements are then forwarded to the Master Control Agent, who spreads them to all the Local Control Agents, so they can apply a proper control action in terms of a new short-term power setpoint. The Local Control Agent use some control parameters sent by the Master Control Agent in order to compute such new power setpoints. These parameters are updated each time the "slow" Scheduling is computed by the Master Control Agent. While the "slow" scheduling computed by the Master Control Agent is sent to the E-Mobility Platform and then sent via 5G communication to the Charging Stations and then actuated to the EVs, the new short-term power setpoints computed by the Local Control Agents are sent via 5G communication to the IoT Agents of the Charging Stations and override the "slow" scheduling, in order to provide fast response to frequency deviations. In details, in the Frequency Control loop the following messages are exchanged: the Frequency Meter installed on the Master Charging Station collects Frequency Measures from the Electricity Network and sends them to its Local Control Agent; the Local Control Agent forwards the frequency measurement to the Master Control Agent, that spreads it to all the Local Control Agents; all these communications are done using 5G technology in order to be able to match the very strict time constraints needed for that Frequency Control exploiting URRLC services of 5G technology. Then, each Local Control Agent computes a new short-term power setpoint based on the Frequency Measurements and on the Control Parameters received. At the end all the relevant business KPIs collected in the loops are sent to the 5G-Solutions KPI Visualization System.

In the last messages group, the Experimenter sends a Stop Experiment message to the Master Control Agent that in turns stops the 5G-Solutions KPI Visualization System and notify the Experimenter that the experiment is successfully finished.

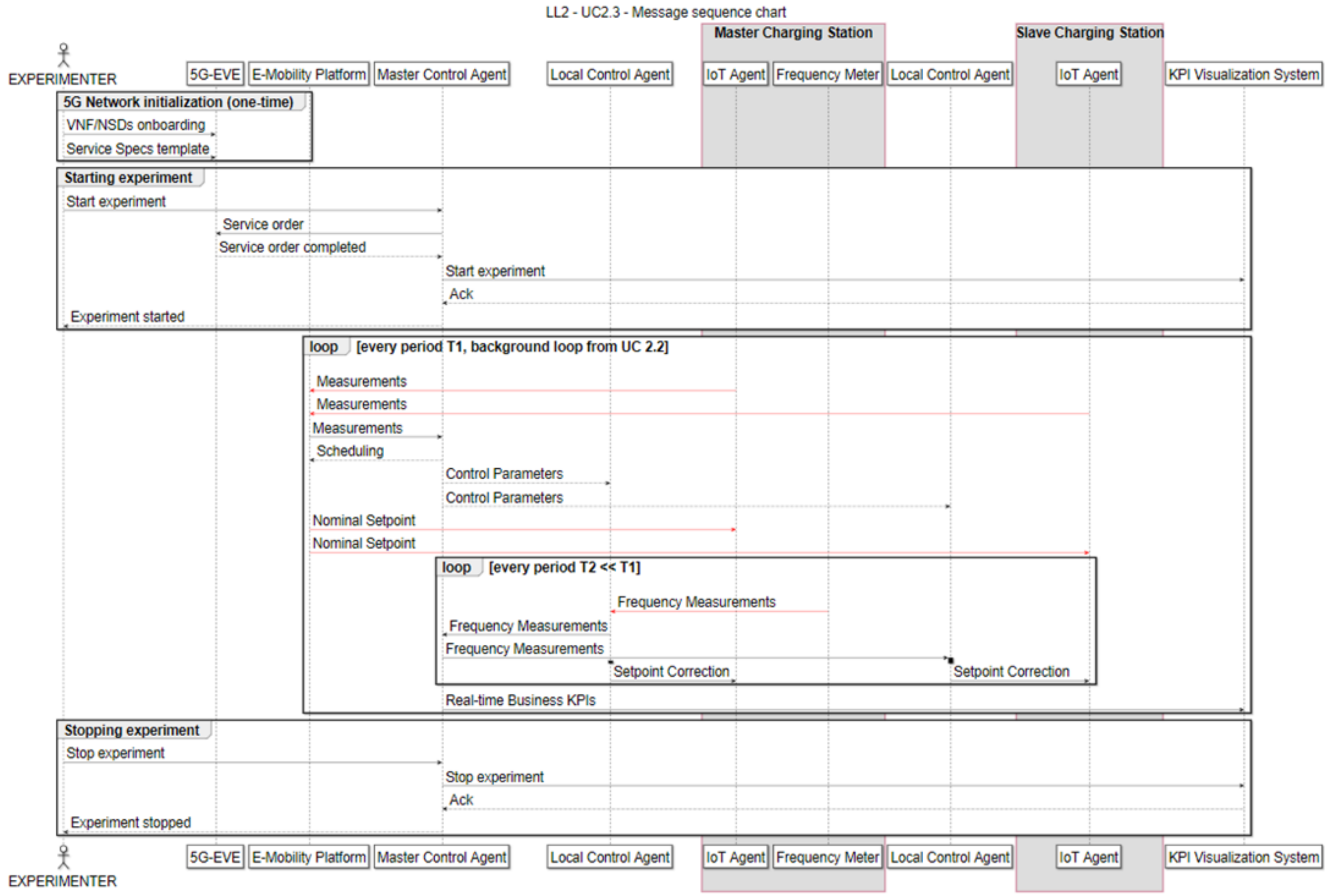

Figure 42: UC2.3 – Message Sequence Chart

5.2.3.4 *Collaboration with the testbeds and deployment*

The collaboration with the testbed hosted by the ICT17 5G EVE Platform is active. The coverage of the test area for running all test cases (TC 2.3.1 and TC 2.3.2, including pre-trial test case 2.3.0) has been confirmed by the Italian Site Manager (TIM). The covered area for all test cases in UC2.3 includes two parking areas at IREN's and Enel's premises in the yellow polygon as showed in the Figure 43.

Figure 43: UC2.3 – Area of interest for trials

The main roles for the UC 2.3 will be named and played as follows:

- 5G-Solutions Use Case responsible – Enel X
- 5G-Solutions VNF producer – Ares2t
- 5G-Solutions Use Case developer partner – Ares2t

In Cycle 1, test case TC 2.3.0 will be managed in line with the Experiment Flow Activities proposed by ICT17 project 5G EVE. The aim of the Experiment Flow Activities is the execution of test cases in the indicated area of interest, the test, the validation and the demonstration of each test case in real conditions, and the collection, validation and report of relevant KPIs, including network and business KPIs. The activities are organized in four groups:

1. **Experiment Design** – The experiment is conceived and evaluated in terms of feasibility by the 5G-Solutions Use Case responsible and 5G-Solutions Use Case developer. Necessary VNF package is on-boarded by 5G-Solutions VNF producer supported by the Site Manager. The experiment is fully specified by G-Solutions Use Case developer that provides the Vertical Service definition and, accordingly, the Experiment definition.
2. **Experiment Preparation** – The experiment is customized by the 5G-Solutions Use Case responsible according to different network scenarios of interest from the operation and business point of view. The experiment is scheduled by 5G-Solutions Use Case responsible in accordance with the Site Manager, who manages the experiment environment with respect to customization and scheduling.
3. **Experiment Execution** – The experiment is instantiated and executed under the supervision of the 5G-Solutions Use Case responsible. Measurements of network and business KPIs of interest are collected.
4. **Results Analysis** – The results from the experiment, including the experiment measurements, are analysed and evaluated by the 5G-Solutions Use Case responsible.

Each group of Activities involves one or more actors according to the above-mentioned roles. These actors will play their role trough the 5G EVE Portal via web access. In UC2.3, the actors will be Enel X and Ares2t supported by TIM as Site Manager in steps 1 and 2.

Currently, the test case TC 2.3.0 in UC 2.3 selected for Cycle 1 is in the Experiment Design phase, according to the Experiment Flow Activities and the Terms and Conditions issued by the ICT17 project 5G EVE. The complete integration process will be described in deliverable D2.1 "Setup and operation of 5G infrastructure".

5.2.3.5 *Trials planning*

Trials planning for Cycle 1 concerns test case TC 2.3.0. The plan has been discussed by Use Case responsible (Enel X) and the technological partners involved in UC2.3, namely Ares2t (as VNF producer and Use Case developer) and TIM as Site Manager of the Italian Site in 5G EVE Facility. The plan is the following one:

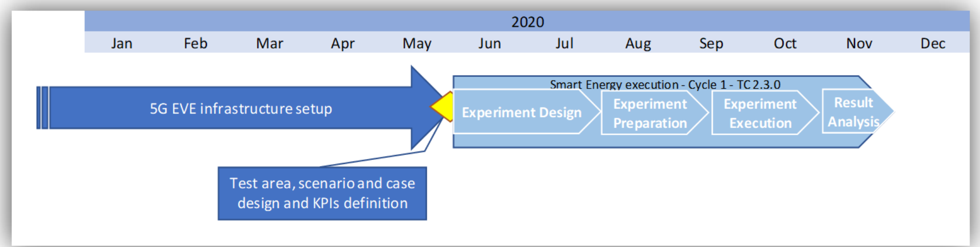

Figure 44: UC2.3 Trials Planning

5.2.3.6 *Planned KPIs to be tested*

As pre-trial test case, TC 2.3.0 aims at verifying coverage conditions in the area indicated in Figure 43. Relevant KPIs are network *reliability* and *latency* in the covered area in different context scenarios (e.g., with delay, packet loss, etc.) to simulate actual situations impacting on timing and processing capabilities of the control-based management procedures being under developing for Cycle 2. Reference measurements will impact on analogous test cases in Cycle 2 and Cycle 3 in presence of actual energy load and network traffic.

5.2.3.7 *Test Cases*

Table 24: UC2.3 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC2.3-PRE	Pre-trial unit and integration test	N-SC	Default scenario and simple network configuration to test connectivity and preliminary integration	Preliminary communication and setup test
UC2.3-SC1	Frequency regulation sessions	U-SC, N-SC	Simulate frequency regulation services using V1G charging stations	Evaluate the pros/cons of 5G communication for reliability, flexibility and latency when sending live usage data from the field to the back-end and receiving modulation signals for frequency regulation from the back-end to the charging station.

Table 25: UC2.3 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC2.3-TA1	E2E 5G communication between 5G EVE facility and mobile device - Test	Unit, Component Test	End to end communication will be tested in the Italian Site of the facility 5G EVE. A 5G mobile device equipped with suitable SIM card will be used to verify the connection with the MEC server located in the facility	To test the 5G communication infrastructure from 5G EVE is working properly on the pilot area
UC2.3-TA2	Charging points	Unit,	Charging points integration with 5G	Test the integration

	test area preparation	Component Test	infrastructure (modem/SIM integration); check the communication with backend system	of systems and their functionalities
UC2.3-TA3	Frequency regulation services simulation area	Integration Test	Simulate signal from DSO/TSO for adapting power consumption in order to regulate grid frequency. In this particular use case, the input signal will be sent to the frequency meter installed in the master charging station and cluster management will be achieved by sending information from the master charging station to the back-end and from the back-end to the slave charging stations using 5G networks. The charging power to the EVs will be modified accordingly to fulfill grid frequency regulation requests.	Test the integration of systems and their functionalities

Table 26: UC2.3 TCs Matrix

	TC01	TC02	TC03
Test Areas	UC2.3-TA1	UC2.3-TA2	UC2.3-TA3
Target Vertical KPIs - Primary & Secondary			
Reliability	1st	1st	1st
Latency	2nd	2nd	2nd
Area traffic capacity	2nd	2nd	2nd
Successful data pushing rate (pushing measurements and receiving dispatching orders		1st	1st
Energy flow, charging sessions and duration during tests		1st	1st
unbalancing comparison to dispatching order (due to communication problems)			1st
Scenario ID			
UC2.3-PRE	2.3.0		
UC2.3-SC1		2.3.1	2.3.2

5.3 LL3: Smart Cities & Ports

5.3.1 UC3.1: Intelligent street lighting

5.3.1.1 *UC test objective and design*

"Intelligent street lights" is an IoT solution that is developed for cities with the goal of reducing the energy consumption by street lights. To do so, the street lights would be fitted with a sensor that can send movement data to the system and this system then determines the state in which the particular street light should be in, such as switch on, switched off or dimmed. To showcase the use case in the city, the tests have to be designed so that they can ensure 100% reliability on the data being collected and performance data.

To do so we are running a virtual City in our Realtime Application which simulates the sensors triggered by the simulated traffic and then send out their data to the Grid Aggregation AFs (Application Functions). These AFs send all their data to the cloud AF, which controls the whole environment. The simulation produces a visualization of the traffic movement in a virtual city built using the Unity3D game engine.

From their reactions based on the calculated data from the Grid Aggregation, AFs will be sent back to the (virtual) Sensors that are in the Street Lights. The Simulation will not only trigger the sensors, but also display the reactions and instructions from the cloud AF. The cloud AF is also going to be responsible for calculating the energy usage in the city and can determine the difference between scenarios when the sensors are not available and with the sensors, to determine the effect Intelligent Street lights will have on the energy consumption.

This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.3.1.2 *Test planning*

This GANTT chart represents the planning for Cycle 1 trials.

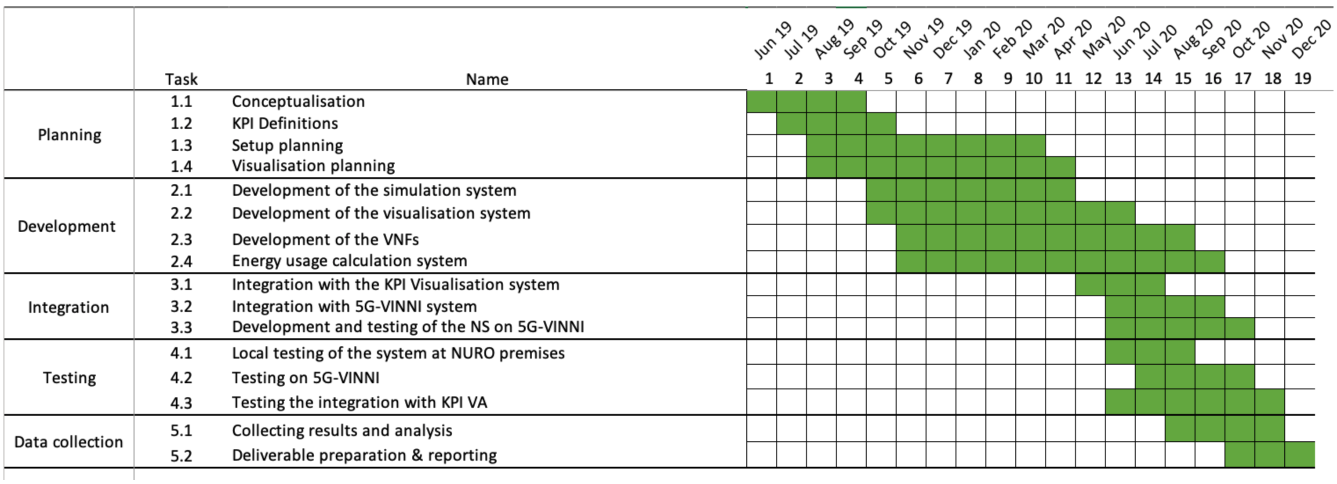

Figure 45: UC3.1 Test Planning

5.3.1.3 *UC Architecture and Information flow*

Figure 47 shows how the street lights are connected to local compute units as well as with the entire system using a series of decentralized aggregators.

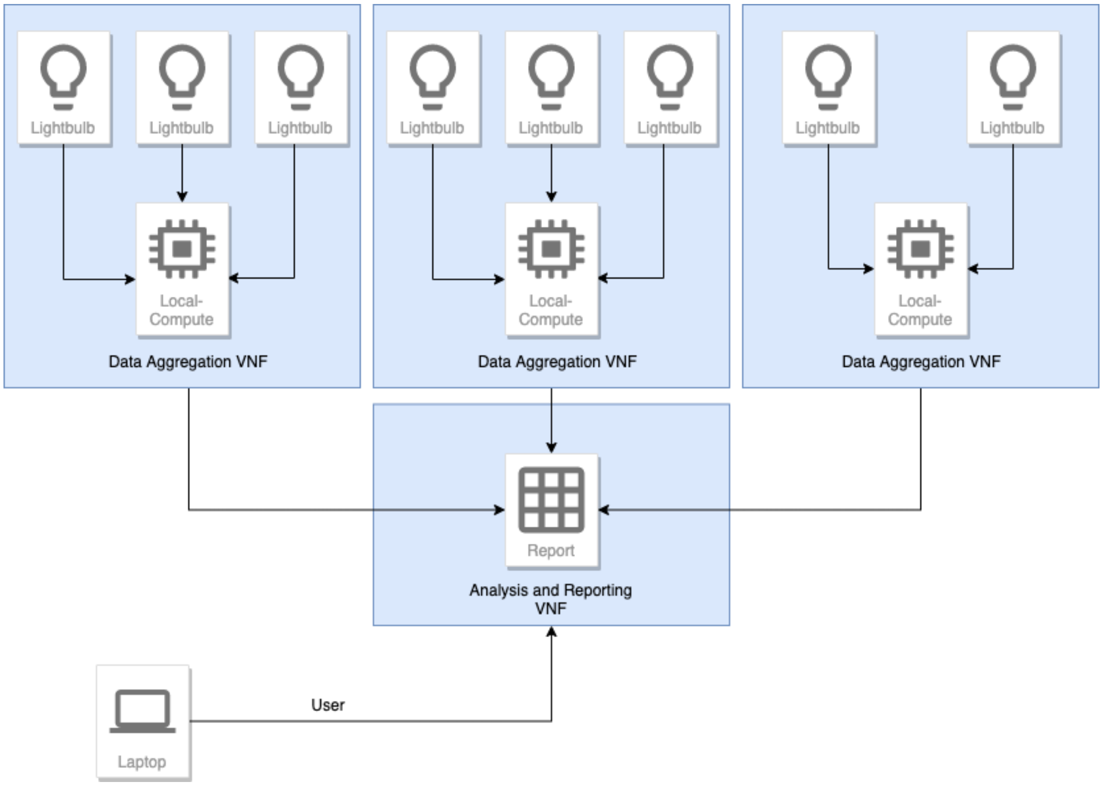

Figure 46: High level Architecture - UC3.1 Operation

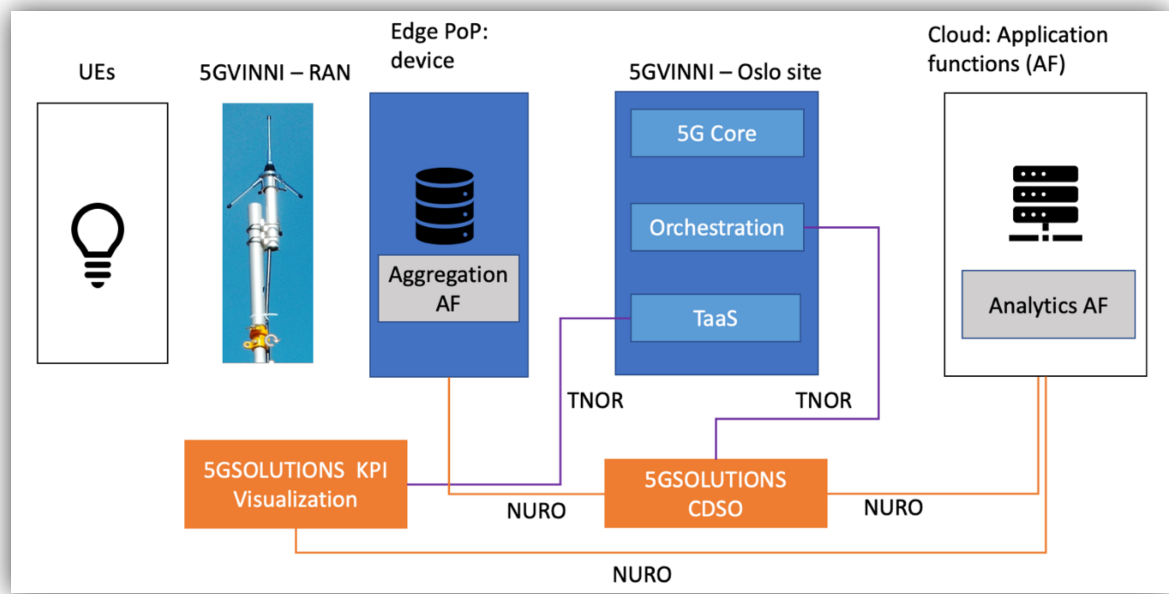

Figure 47: High level Architecture - UC3.1 Management

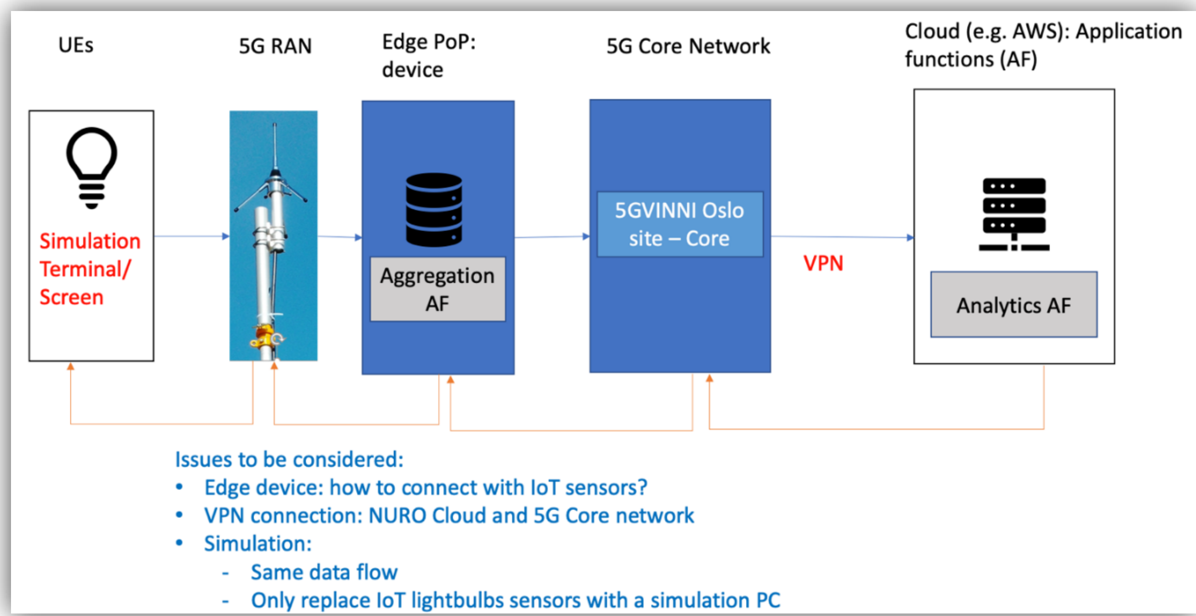

Figure 48: High level Architecture - UC3.1 Cycle 1 Implementation

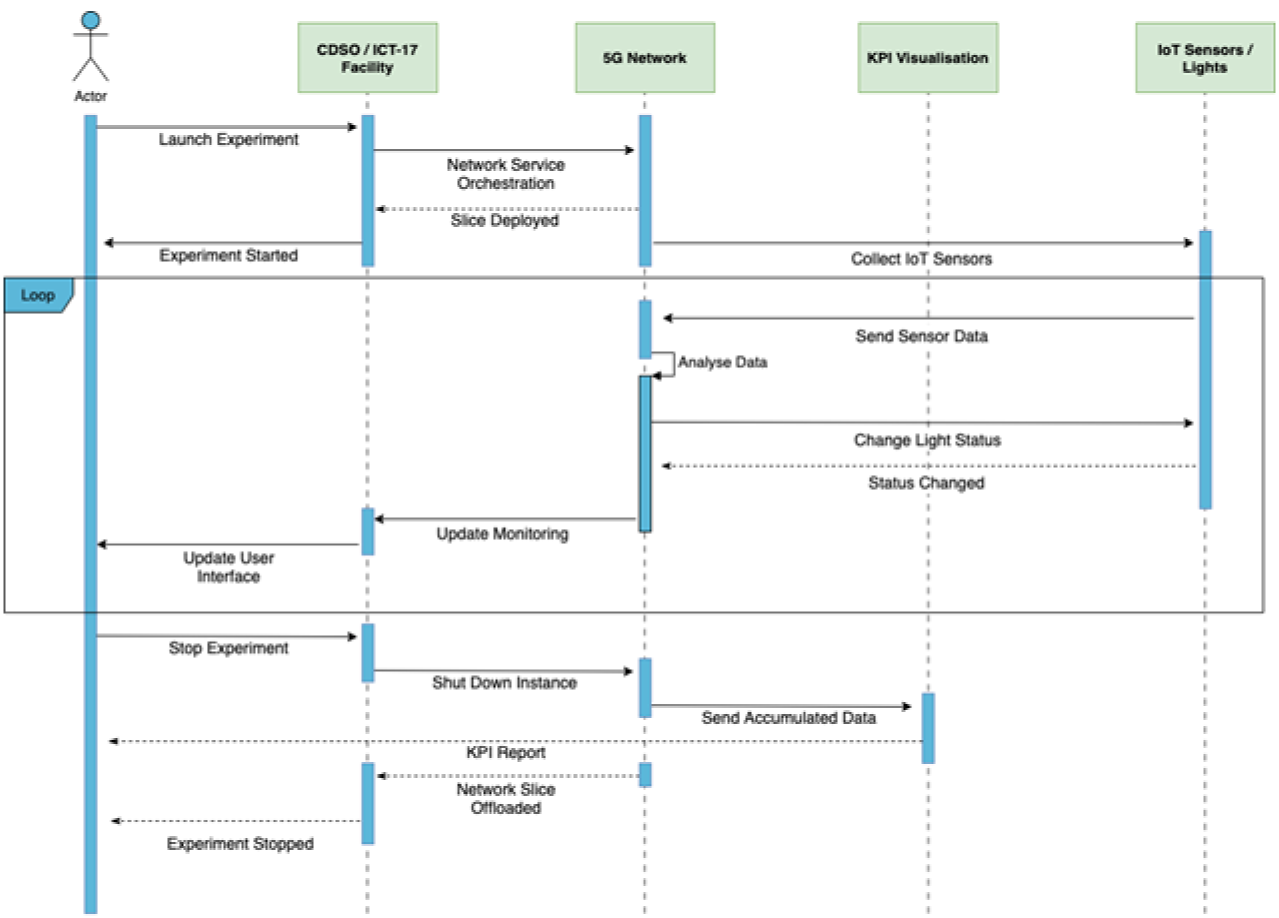

Figure 49: Data Flow diagram - UC3.1

The data flow diagram in Figure 49 showcases how we plan to send data across the 5G testbed and the KPI Visualization System and IoT sensors.

For KPI Visualization System the following data-model is developed:

```
// We have a grid of several streetlights grouped together
// Every cell provides the following information
StreetLightCellInfo
{
    currentNumberOfActiveLights: <int>,
    currentNumberOfActiveMovements: <int>,
    currentAverageIlluminance: <float> in Lux
    todayActiveTime: <int> in s
}

// The master node aggregates all info and calculates advanced reactions
StreetLightMasterInfo
{
    currentTotalNumberOfActiveLights: <int>,
    currentTotalNumberOfActiveMovements: <int>,
    currentTotalAverageIlluminance: <float> in Lux
    todayTotalActiveTime: <int> in s,
    todayTotalPowerConsumption: <int> in kwh

    [   // For every Cell
        {
            cellID: <string>,
            averagePingToCell: <int> in ms,
            averagePingFromCell: <int> in ms,
            powerConsumptionToday: <int> in kwh
            lastCellInfo: <StreetLightCellInfo>
        }
    ]
}
```

Figure 50: UC3.1 Data model for Visualization

5.3.1.4 *Collaboration with the testbeds and deployment*

The collaboration with the 5G-VINNI network and testbed includes three parts: i) deployment of the NURO application functions (AF) interconnected with the 5G network; ii) integration with the 5G-VINNI orchestration system via 5GSOLUTIONS CDSO to manage and orchestrate the E2E service; iii) integration with the 5G-VINNI testing platform TaaS via 5GSOLUTIONS KPI visualization system to collect measurement data and visualization service KPIs. In Cycle 1, as CDSO is not planned for the 5G-VINNI Norway facility, the collaboration effort focuses on i) and iii).

Deployment of AFs

There are two types of NURO AFs, Aggregation AF and Analytics AF, to be deployed in UC3.1. The Aggregation AFs are planned to be deployed in an edge device (e.g., a laptop) close to the lightbulb sensors. They collect sensing data from the lightbulb sensors and send aggregated data and process them, and then send the processed results to the Analytics AF. The Analytics AF is deployed in a cloud (e.g., AWS or co-located in the 5G-VINNI Norway facility datacentre) and analyses all data from the Aggregation AFs to produce instructions to change the lightbulb status, which are sent back and forwarded by the Aggregation AFs to lightbulbs.

Deployment of simulation program

In Cycle 1, a simulation program is launched to simulate the traffic generated by lightbulbs and visualize the status of street lights: switch on, switched off or dimmed, based on the instructions produced by the Analytics AF. The machine hosting this simulation program is planned to be deployed in a location near the street lights, where the sensors will be installed in Cycle 2. The machine should be capable of connecting to the 5G RAN node.

Integration with 5G-VINNI testing platform (TaaS)

In Cycle 1, as the CDSO will not be activated for the 5G-VINNI Norway facility, the testing management is not automated. Therefore, all the tests will be conducted manually (e.g., start and stop tests via Test as a Service (TaaS) GUI in 5G-VINNI). The main integration occurs with the 5GSOLUTIONS KPI visualization system (KPI VSI). In Cycle 1, a database (for UCs including UC3.1) will be developed in the 5GSOLUTIONS KPI Visualization system and used for storing the data retrieved from the TaaS of 5G-VINNI. The TaaS will be used to measure 5G network KPIs using monitoring tools that can be installed both inside and outside of the 5G-VINNI network. The integration of the 5GSOLUTIONS KPI visualization system with the 5G-VINNI TaaS system will only be partly implemented in Cycle 1.

5.3.1.5 *Planned KPIs to be tested*

Table 27: UC3.1 Reference KPIs

Use Case		**Latency (ms)**	**Connection density (device/m^2)**	**Reliability (%)**	**Coverage (%)**
UC3.1	Expected	<100	>1	>99	>99

5.3.1.6 *Test cases*

UC3.1 is best effort as described in the beginning of the document. Test cases will be defined at a later stage.

Different scenarios will be developed and tested. All the scenarios will be detailed with input from city chosen for final execution of the Use case. In the cycle 2, we will be testing real environment with visual dashboard for the administrator.

5.3.2 UC3.2: Smart Parking

5.3.2.1 *UC Test objective and Design*

Smart parking and data analytics solutions can be envisioned as an integrated system of ICT and urban infrastructure development. Parking inside buildings and on streets can be monetized, if the development is linked with data analytics driven customer facing app where information is made available transparently to citizens looking to find parking spots in the city. When designing smart parking solutions, creating an intuitive GIS enabled app that synchronizes with the GPS location of a customer's mobile device and informs citizens of available parking slots in their vicinity can increase the usage of the smart parking facility.

The primary objective of this UC is to allow drivers to look for inter-city parking spaces so as to easily spot the most convenient and available parking places. Smart parking solutions aim to reduce congestion, emissions and improve traffic safety allowing at the same time higher quality of life for the residents. A smart parking system can benefit not only the drivers and the operators but the city councils as well. Smart parking saves time and costs for the drivers, whereas municipalities are able to provide a more efficient traffic guidance increasing their profits while complying with relevant emissions requirements[12]. UC3.2 shall include 4K cameras installed over the parking spot for monitoring the parking space in real-time and providing the information to the user via the mobile application. The concept design can be seen in Figure 51.

[12] *https://www.siemens.com/content/dam/webassetpool/mam/tag-siemens-com/smdb/mobility/road/parking-solutions/integrated-smartparking/documents/smart-parking-brochure2.pdf*

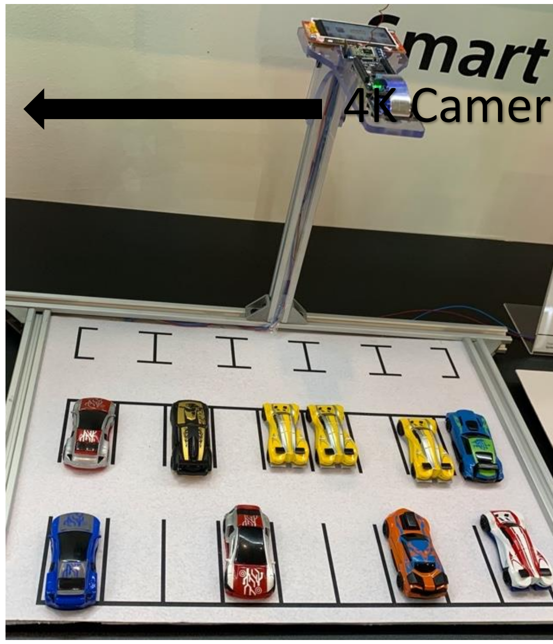

Figure 51: UC3.2 Concept Design

The purposes of having a camera for smart parking application instead of sensors are:

- Camera can be multi-purpose, like theft monitoring, safety monitoring of the surroundings.
- Cost effective in long term.

The implementation of UC3.2 passes over two main Cycles. In Cycle 1, implementation of the 5G-VINNI testbed at Telenor Campus is carried out, including deployment of 5G base station and 5G-enabled endpoints. This also includes integration of simulation for smart parking application together with the UC3.1 and with the KPI visualization system. The data model that shall be taken in this UC is defined as for Off Street Parking & On Street Parking. This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

5.3.2.2 *Test planning*

The Gantt chart below is presenting the timeline for Cycle 1 for UC3.2. The use case will further complete during the Cycle 2 phase.

	Task	Name	Jan 20 1	Feb 20 2	Mar 20 3	Apr 20 4	Apr 20 5	May 20 6	Jun 20 7	Jul 20 8	Aug 20 9	Sep 20 10	Oct 20 11	Nov 20 12	Dec 20 13
Planning	1.1	Conceptualisation	■	■	■	■									
	1.2	KPI Definitions		■	■	■	■								
	1.3	Setup planning			■	■	■	■	■	■	■	■			
	1.4	Application development planning			■	■	■	■	■	■	■	■	■		
Development	2.1	Development of the simulation system						■	■	■	■	■	■	■	
	2.2	Development of the VNFs						■	■	■	■	■	■	■	■
	2.3	Parking utilisation system calculation						■	■	■	■	■	■	■	■
	2.4	Development of mobile application												■	■
Integration	3.1	Integration with the KPI Visualisation system												■	■
	3.2	Integration with 5G-VINNI system													■
	3.3	Development and testing of the NS on 5G-VINNI													■
Testing	4.1	Local testing of the system at NURO premises											■	■	■
	4.2	Testing on 5G-VINNI													■
	4.3	Testing the integration with KPI VA													■
	4.4	Testing on Parking Site													
Data collection	5.1	Collecting results and analysis													■
	5.2	Deliverable preparation & reporting													

Table 28: UC3.2 Test Planning

5.3.2.3 *UC Architecture and Information flow*

The detailed architecture of UC3.2 has been shown in Figure 52. As it has been depicted in the figure, a camera on parking spot is connected with micro-controller as edge computer to analyze the situation and provide the information to the 5G network via NB-IoT. VNFs will be deployed on the 5G-VINNI testbed at Norway facility.

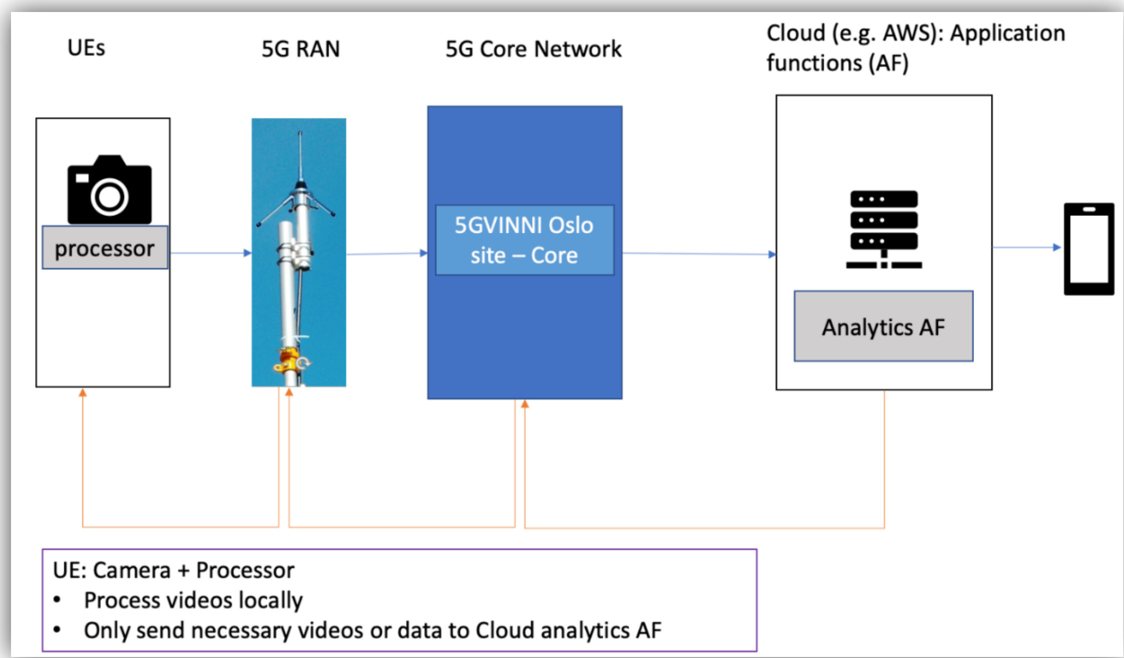

Figure 52: High Level Architecture UC3.2 Operation

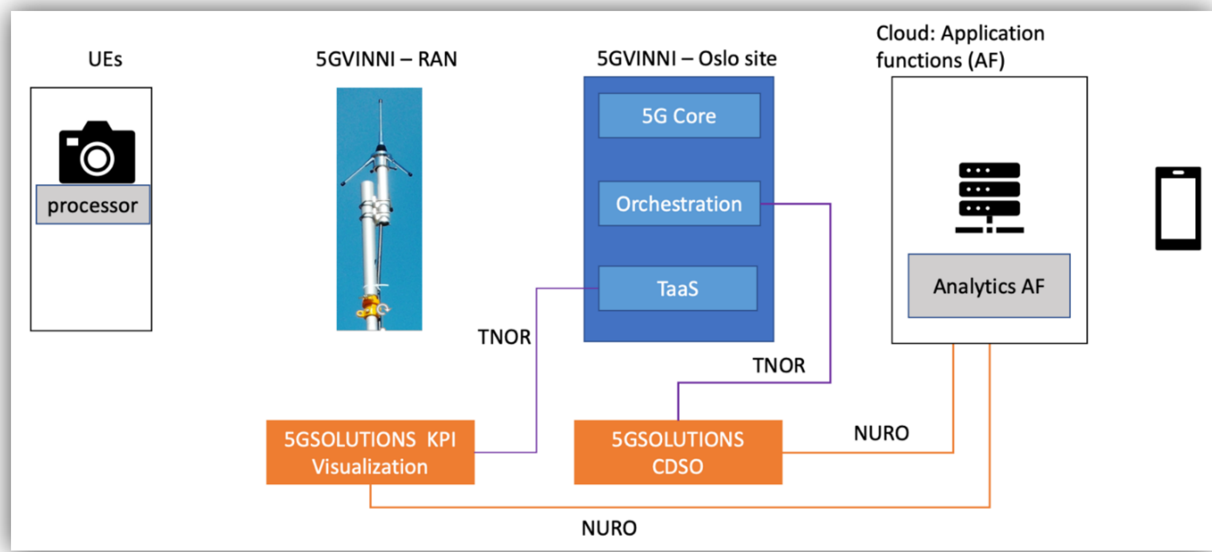

Figure 53: High Level Architecture UC3.2 Management

Figure 54 shows the high-level architecture of the setup of the simulation along with the connections to the VHFs as well as other 5G-Solution systems such as KPI Vs and CDSO.

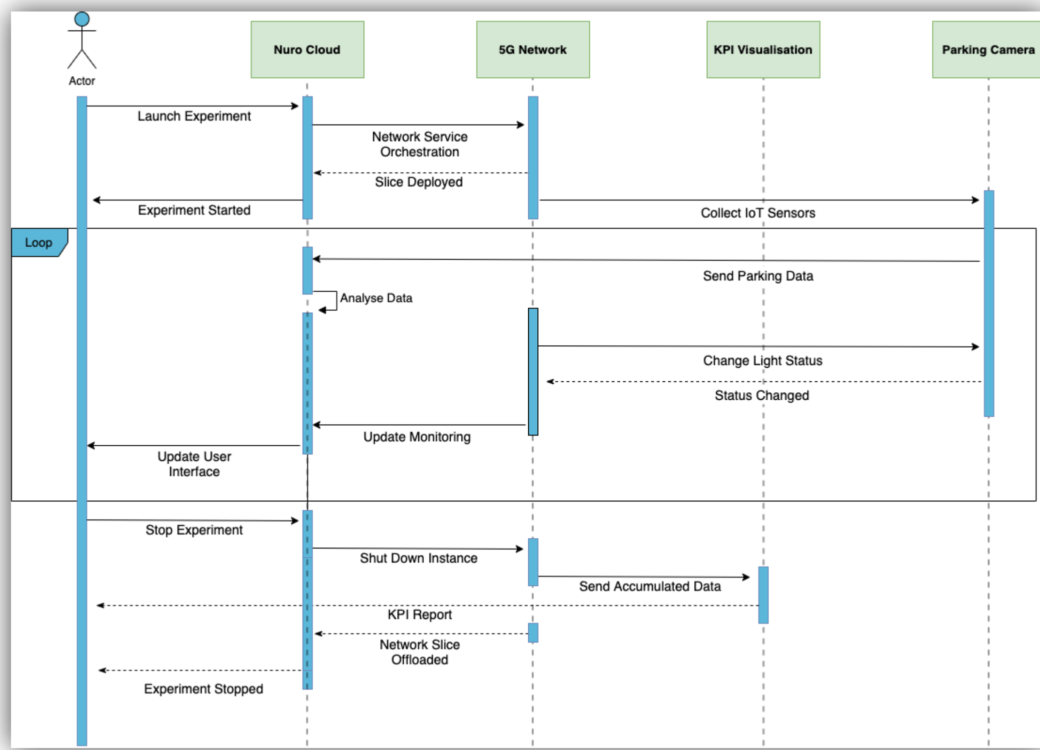

Figure 54: UC3.2 Information Flow

Figure 54 is depicting the flow of data during the complete life cycle of application. There will be five actors involved in the application.

The data model and the associated Rest APIs results are included in Annex I.

5.3.2.4 *Collaboration with the testbeds and deployment*

The collaboration with the 5G-VINNI network and testbed includes three parts: i) deployment of the NURO application functions (AF) interconnected with the 5G network; ii) integration with the 5G-VINNI orchestration system via 5G-SOLUTIONS CDSO to manage and orchestrate the E2E service; iii) integration with the 5G-VINNI testing platform TaaS via 5GSOLUTIONS KPI visualization system to collect measurement data and visualization service KPIs. In Cycle 1, as CDSO is not planned for the 5G-VINNI Norway facility, the collaboration effort focuses on i) and iii).

Deployment of AFs

There are two types of NURO AFs, Aggregation AF and Analytics AF, to be deployed in UC3.1. The Aggregation AFs are planned to be deployed inside the cameras, as part of the UE. They collect and process the videos directly and then send the processed results to the Analytics AF. In principle, only a small part of data is transmitted to the Analytics AF. The Analytics AF is deployed in a cloud (e.g., AWS or co-located in the 5GVINNI Norway facility datacentre) and analyses all data from the Aggregation AFs to produce real-time parking information and guidance to the users via a mobile app.

To be planned and decided: the cloud hosting the Analytics AF (public cloud or 5G-VINNI Norway facility cloud)

Deployment of simulation program

In Cycle 1, a simulation program is launched to simulate the video data generated by parking cameras. The machine hosting this simulation program is planned to be deployed in a location near the campus where the parked cars will be located in Cycle 2. The machine should be capable of connecting to the 5G RAN node.

Integration with 5G-VINNI testing platform (TaaS)

In Cycle 1, as the CDSO will not be activated for the 5G-VINNI Norway facility, the testing management is not automated. Therefore, all the tests will be conducted manually (e.g., start and stop tests via Test as a Service (TaaS) GUI in 5G-VINNI). The main integration occurs with the 5GSOLUTIONS KPI visualization system (KPI VSI). In Cycle 1, a database (for UCs including UC3.2) will be developed in the 5GSOLUTIONS KPI Visualization system and used for storing the data retrieved from the TaaS of 5G-VINNI. The TaaS will be used to measure 5G network KPIs using monitoring tools that can be installed both inside and outside of the 5G-VINNI network. The integration of the 5GSOLUTIONS KPI visualization system with the 5G-VINNI TaaS system will only be partly implemented in Cycle 1.

5.3.2.5 *Expected results (KPIs vs reference KPIs)*

Table 29: UC3.2 Expected results

Use Case		Mobility	Latency (ms)	Connection density (device/m^2)	Reliability (%)	Positioning Accuracy (m)	Coverage (%)
UC3.2	Expected	<100	<100	>0.1	>95	<10	>99

5.3.2.6 *Test Cases*

UC3.2 is a best effort one as described in the beginning of the document. Test cases will be defined at a later stage.

In Cycle 1, a simulated environment will be used and trials will be planned accordingly with all the tests happening in the simulated environment. In further cycles, the real environment with a Mobile app for the end users will be used.

5.3.3 UC3.4: Smart buildings / Smart campus

5.3.3.1 *UC Test objective and Design*

The past few years have witnessed a tremendous increase in the use of IoT sensors and security surveillance devices to track building systems, maximize their efficiency, and maintain a comfortable and productive work environment. This has facilitated a wide range of applications and use cases including, but not limited to, smart lightening, HVAC energy deduction, smart reading, building utilities monitoring, fire control, access control, and energy usage. For instance, IoT sensors are being used to detect whether a building is empty and adjust power to the area accordingly to conserve electricity or gas. In addition, unusual activities can be immediately detected by surveillance cameras and IoT devices and, accordingly, notifications can be sent in real time. As a result, the number of on-campus incidents has been significantly reduced. Campus statistics showed that up to 80% of lost items are retrieved, and the return rate of lost or stolen items has increased from 20 percent to 60 to 80 percent.[13]

Motivated by the increasing importance of such smart environments, this use case aims at devising an Innovative solution to enable true transformation towards smart campus/buildings. This use case will leverage the most advanced and next-generation emerging technologies so as to facilitate frictionless, touchless, and intuitive experiences driven by a digitally connected environment. In particular, this use case will focus on two main scenarios, namely, cooperative positioning and predictive maintenance for IoT devices, and enhanced security monitoring and anomaly detection based on ultra-high resolution 4K cameras.

In detail, this use case will implement cooperative positioning and predictive maintenance for IoT devices, which are deemed key enablers for smart campus/building technology. The proposed approach will replace the current reactive maintenance approaches, wherein devices' maintenance is carried out either upon recognizing system failure or according to scheduled maintenance cycles. Our ultimate target is to adequately reduce the manpower needed for scheduled maintenance, achieve virtually automated maintenance schemes, and avoid service disruption and system failure. We also aim at prolonging the life span of IoT sensors/devices via adopting proper power saving modes based on the dynamic of the environment, thereby increasing system reliability and reducing energy consumption and maintenance costs. All of these desirable aspects would help make a profitable business for smart campus/building technology. Towards this objective, and driven by real time monitoring and historical information of the devices' status and the underlying environment, novel machine learning algorithms and analytics based on, e.g., support vector machine (SVM) and deep learning will be developed to predict when an IoT device needs maintenance and if the received measurement is an anomaly.

To this end, accurate indoor positioning will be vital to enable successful operation and predicative maintenance of smart industrial IoTs. For example, exact locations of the sensors/devices could be easily lost due to regular maintenance and frequent repositioning. This issue will be notoriously more challenging for mMTC where thousands of IoT devices are deployed. Moreover, if the sensors are mobile for applications such as asset tracking, last-mile indoor delivery robots, or indoor aerial surveillance, precise positioning will be as crucial as the information about the environment itself.[14] Therefore, maintaining accurate indoor positioning is of utmost importance for the transformation towards smart campus/buildings. In this regard, this use case aims at providing accurate indoor positioning information for each connected IoT device driven by the most advanced and next-generation wireless technologies.

Finally, this use case will advance the security surveillance by providing an ultra-reliable security monitoring solution for smart campus/buildings, driven by advanced video analytics and machine learning techniques, and ultra-high-resolution cameras. In detail, according to Accenture, around 98% of video footage is not reviewed

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[13] https://www.intel.pl/content/www/pl/pl/smart-buildings/end-to-end-smart-campus-solution-brief.html

[14] Prophet, Silvia, Jamal Atman, and Gert F. Trommer. "A synergetic approach to indoor navigation and mapping for aerial reconnaissance and surveillance." International Conference on Indoor Positioning and Indoor Navigation (IPIN). IEEE, 2017.

by anyone.[15] With the tremendous increase of the number of deployed surveillance cameras, CCTV operators will struggle to view all the footage to monitor real-time events. By relying on the available manpower, such traditional approaches take a considerably large amount of time for reactive anomaly detection and post-incident analysis, while also being susceptible to errors of manual interventions. Indeed, this renders the physical security of smart campus/buildings very inadequate.

This use case therefore aims at adopting novel machine learning algorithms and cloud-based analytics to intelligently detect anomaly and objects and monitor behaviors in smart campus/buildings, driven by very detailed footage from ultra-high resolution 4K cameras. In particular, cellular-connected 4k cameras deployed in secure areas will be used to identify nearby abnormality and recognize various objects based on their very detailed footage capability. The use of 4K video cameras will then pave the road for more advanced machine learning algorithms and analytics techniques for video surveillance systems capable of revolutionizing automated anomaly/object detection compared to current systems, without the errors of manual intervention. Such enhanced security mentoring is expected to yield a considerable reduction in false positive alerts without a decrease in the anomaly detection accuracy (true positives).

Cooperative positioning and predictive maintenance hand in hand with enhanced security monitoring would have a direct impact on the smart campus/buildings business. In this regard, providing seamless connectivity for such a potential large number of IoT devices and surveillance cameras with stringent latency and rate requirements is very challenging. As an example, Intel’s end-to-end Smart Campus Solution for the Chinese Culture University in Taiwan used a private infrastructure to install more than 4,000 sensors along with cameras in the Campus buildings. In contrast, relying on pervasive poor connectivity provided by a few numbers of hotspots can be a limiting factor of the overall performance of smart campus/building technology, which is hard to overcome in a cost-effective way. For example, to extend the WiFi wireless coverage for Kennesaw State University, 3,000 access points are needed to be placed around the campus.[16] Such private infrastructure or WiFi networks are deemed inefficient solutions for smart campus/buildings because of the potential high CAPEX and maintenance OPEX. In addition, WiFi connections incur significantly high energy consumption for the IoT devices.

In this respect, the forthcoming 5G cellular technology stands out as an ideal candidate for preserving reliable and seamless connectivity for such IoT devices and 4K cameras of our use case. 5G technology effectively meets the heterogeneous demand for accurate indoor positioning and predicative maintenance for IoT devices as well as enhanced security monitoring based on ultra-high-resolution cameras. In comparison to 4G’s signals, 5G will be deployed with wide bandwidths located at high frequencies, e.g., Sub-6 GHz and mmWave bands. This enables highly accurate time of arrival and direction of arrival estimation, which are key values towards an accurate positioning system. For example, a raw resolution of below 1 m can be achieved by 5G technology compared to 15 m for the LTE counterpart.[17] In addition, regarding the surveillance cameras, 5G technology can dramatically reduce latency to less than 10 ms and achieve uplink data rate higher than 100 Mbps. As an illustrative example, each 4K camera needs an uplink bit rate of 15 to 25 Mbps and stringent delay requirements, especially for high-quality fast-motion content. In addition, future 8K cameras would push those requirements up to 80 Mbps or even 100 Mbps for each stream.[18] Such rate and latency requirements cannot

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[15] https://www.accenture.com/t20170227t015150__w__/us-en/_acnmedia/accenture/conversion-assets/dotcom/documents/global/pdf/operations_1/accenture-video-analytics-pov-a4-final-webhr.pdf

[16] https://edtechmagazine.com/higher/article/2019/03/higher-education-invests-wi-fi-technology-smart-campus-projects-perfcon

[17] Kanhere, Ojas, and Theodore S. Rappaport. "Position locationing for millimeter wave systems." 2018 IEEE Global Communications Conference (GLOBECOM). IEEE, 2018.

[18] https://www.lightreading.com/video/4k-8k-video/worried-about-bandwidth-for-4k-here-comes-8k!/d/d-id/737330

be supported by current 4G networks, particularly when we factor in multiple cameras streaming simultaneously.[19]

In this respect, the main objective of this UC is to plan, design and conduct a set of two use sub-cases, namely, cooperative positioning and predictive maintenance of IoT devices, and enhanced safety monitoring, by using an agile-based iterative process. The Smart Building & Campus UC will validate KPIs from the two use sub-cases of interest, which have been identified by the 5G-PPP community and the 5G-SOLUTIONS partners as important for the stakeholders of the Smart Building & Campus industry. Particularly, the performance of each sub-case will be measured in technical and business details and benchmarked according to the pre-defined target KPIs. The field trials will be conducted in IBM technology campus in Dublin through a self-contained 5G node, encompassing gNodeB (gNB) and 5G core functionalities, and provided and configured onsite by our partner UoP.

The implementation of UC3.4 passes over two main Cycles. In Cycle 1, implementation of the 5G testbed in IBM Campus is carried out, including deployment of 5G node and 5G-enabled endpoints (i.e., 4K cameras and IoT devices). This also includes integrating the IBM 5G testbed with IBM custom-made analytic server on the cloud and with the KPI visualization system. The integration with the KPI VS will be built upon public internet and peer-to-peer (P2P) VPN connections while the IBM analytics server will be connected to the Blue Zone of the IBM firewall. Throughout Cycle 2, the 5G node will establish a connection with the ICT-17 facility at UoP, and, based on that, engaged with NOKIA's Cloudband Director. This integration will enable a unified end-to-end service orchestration and cross-domain network slicing and 5G service lifecycle automation (e.g., multi-domain network slicing, cross-domain end-to-end orchestration, smart real-time performance monitoring for KPI evaluation, etc.). This use case performed cycle 1 trials.

5.3.3.2 *Testbed Description*

Next, the main elements that form the IBM 5G testbed for UC3.4 are presented. The 5G self-contained node, IoT devices, and 5G-enabled 4K cameras will be deployed in IBM smart campus, and their detailed technical description is as follow:

- Base station: Amari Callbox Classic (https://www.amarisoft.com/products/test-measurements/amari-lte-callbox/) 5G node.
- Cameras: Reolink IP-enabled 4K cameras (3840x2160 pixels) are interconnected to the 5G node via 3rd party, namely, Huawei CPE H112-370.
- IoT devices: Multiple IoT devices operating in the NB-IoT frequency bands are interconnected to the 5G node. The RPis/Arduino-based sensors are plugged into the IoT wireless modules, which have SIM card tray to enable the cellular connectivity with the 5G node. More specifically, we use RPis 4 powered by PiJuice battery HATs. These battery HATs are equipped with 12,000 mAh Lithium-Ion batteries. The PiJuice HAT comes with a 1820mAh as standard, so this 12,000mAh will give us boost in terms of battery life time. In addition, Sixfab cellular modules are used to enable NB-IoT/LTE-M connectivity to the underlying IoT devices.

Please see below screenshot of the adopted 5G user equipment and the serving (Amarisoft) 5G base station.

[19] https://www.4g.co.uk/how-fast-is-4g/

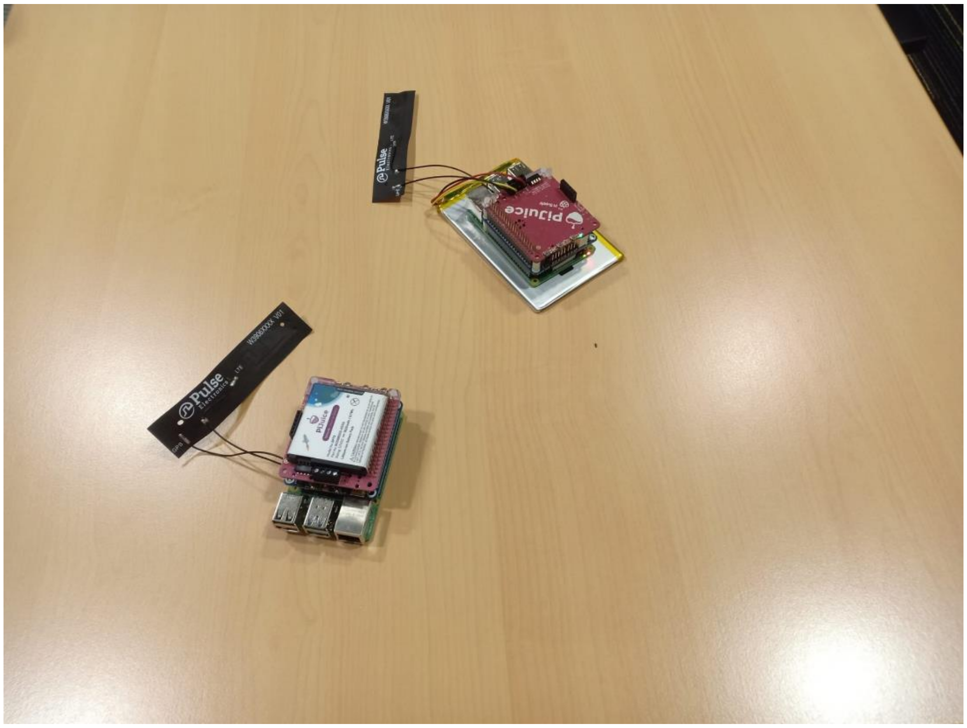

Figure 55: IoT devices composed of Raspberry-Pis 4 and the sensors Sixfab S56 modules

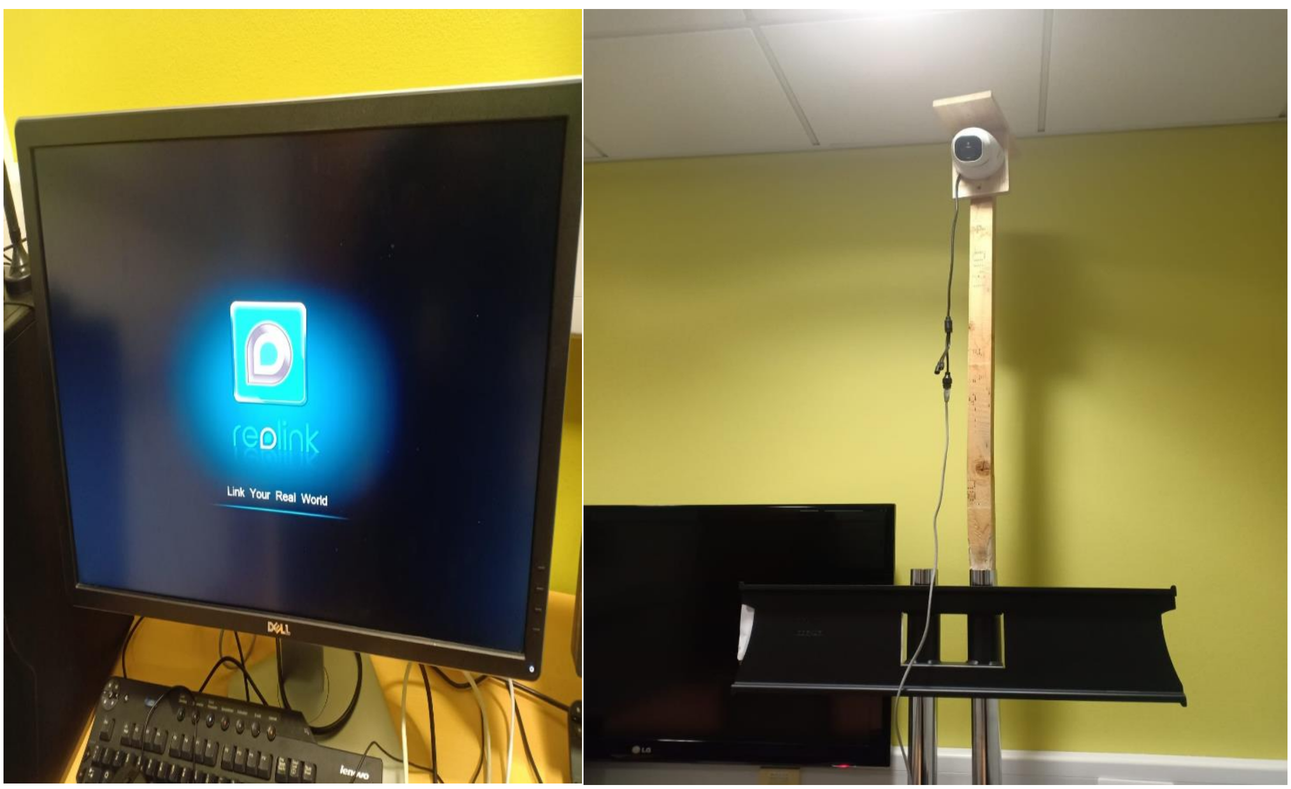

Figure 56: 5G-enabled Reolink 4K cameras and an associated NVR for recording

5.3.3.3 *UC Architecture*

The detailed architecture of UC3.4 during Cycle 1 is presented in Figure 57. During Cycle 1, the 5G testbed in IBM campus has an external connection with the KPI visualization system. In Figure 57, letters A to E refer to the connection types between the various components, which are detailed in the sequel.

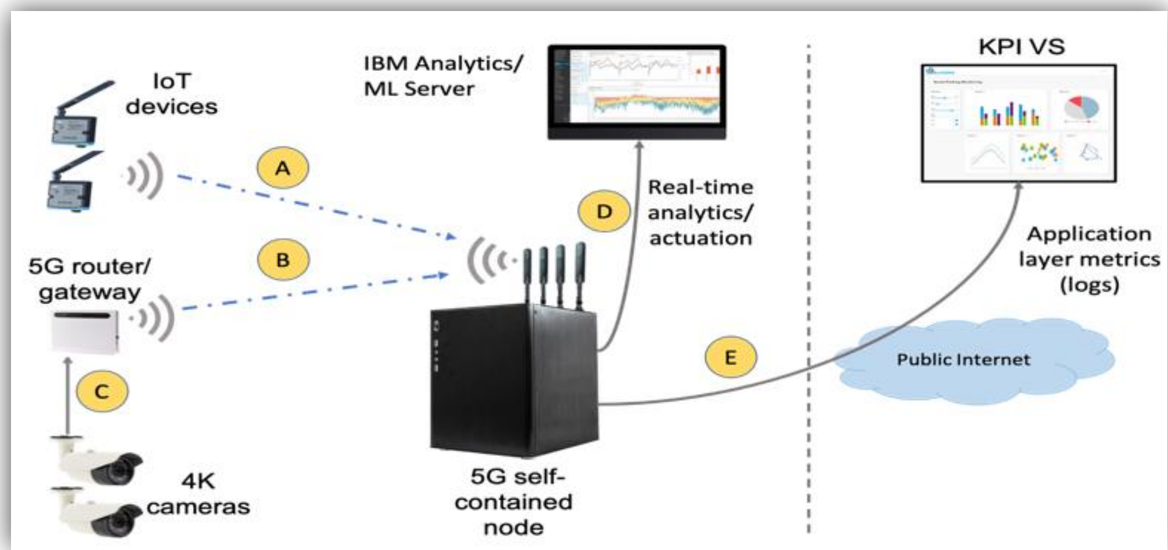

Figure 57: Detailed architecture of UC3.4 during Cycle 1

As illustrated in Figure 57, IoT devices and 4K cameras represent 5G endpoints that engage the 5G self-contained node. IoT devices operate in the NB-IoT band (connection A), whereas the 5G routers/gateways work in the sub-6 GHz, e.g., 3.5-3.6 GHz (connection B). IP-enabled 4K cameras are attached to the 5G node through 5G routers/ gateways, which are connected to the Ethernet ports of the cameras (connection C).

IBM Analytics Server

The IBM 5G node will be integrated with the IBM custom-made analytics server that is reachable from the Blue Zone of the IBM firewall (connection D). The IBM cloud-based server is an analytics server deployed on the IBM cloud. This server will run novel cognitive machine learning techniques and analytical algorithms for fast-real-time analysis and performance validation and optimization. In particular, developed machine learning algorithms will process data feeds to enable successful cooperative positioning and predictive maintenance of IoT devices, and enhanced security and anomaly detection based on live streaming from 4K cameras. Available APIs from the IBM 5G node is used to enable the integration between the server and the 5G self-contained node.

KPI Visualization System

In addition, the IBM 5G self-contained node will establish a connection with the KPI visualization system over the public Internet. The respective application layer integration will be performed via REST APIs provided by the KPI visualization system. This integration will allow near real-time analysis, presentation, benchmarking and performance validation of reference 5G network KPIs against pre-defined target values. Figure 58 below shows the adopted integration between UC3.4 testbed and the KPI-VS based on Websocket API from the base station to the analytical server, and REST-API between the analytical server and the KPI-VS.

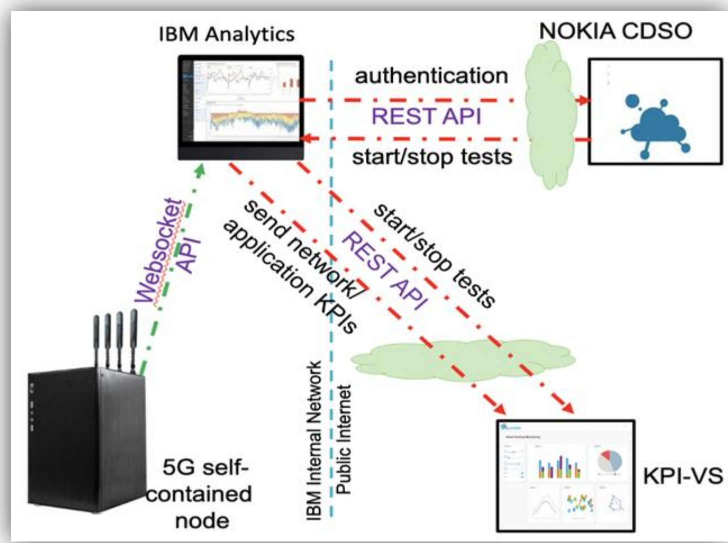

Figure 58: Testbed integration with the KPI-VS (complete setup of Cycle 1)

5.3.3.4 *Information sequence diagram*

A high-level flow diagram of UC3.4 during Cycle 1 is illustrated in Figure 59. As shown in the figure, there are several components that together constitute the test case. Particularly, there exist IBM testbed administrator interacting with the front-end applications, 5G self-contained node in IBM Campus, IBM custom-made analytic server on the private cloud, and the KPI visualization system.

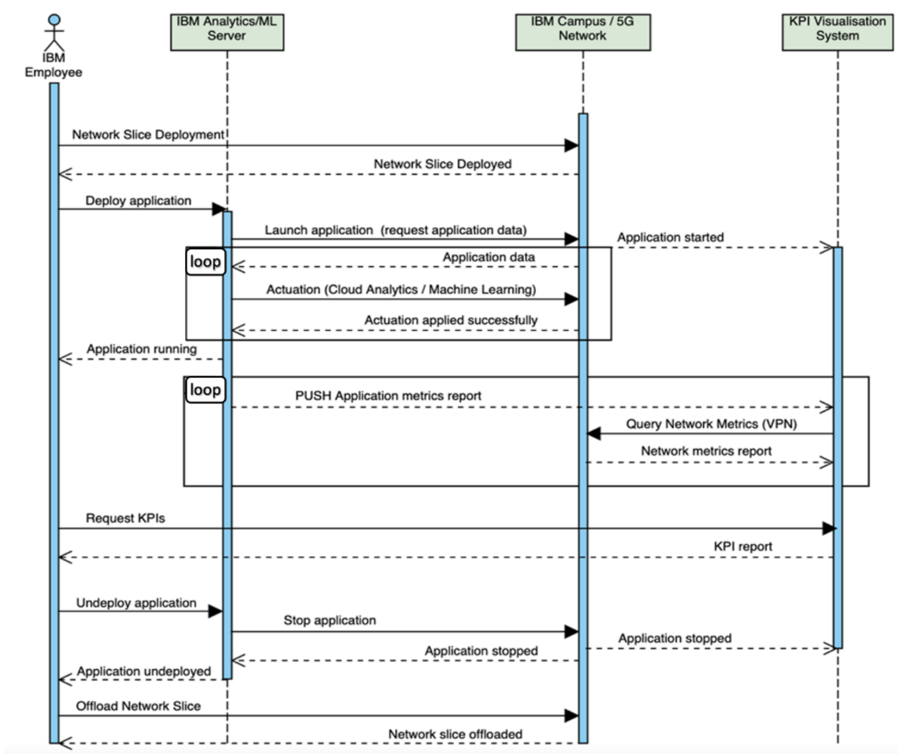

Figure 59: High level information flow diagram for UC3.4 during Cycle 1

For Cycle 1, there are three main steps (or activities) to be executed sequentially towards the deployment and termination of different applications. In the first step, preloaded network slices on the 5G self-contained node are deployed in the 5G node. In the second step, applications of interest can be deployed as follows. The testbed administrator first interacts with the IBM cloud-based server to initiate a specific application on the 5G node. The application is then launched on the 5G node through its interface with the cloud-based server, and the network-related data is retrieved from the node by the server. The IBM cloud-based server is also responsible for notifying the KPI visualization system with the start and end times of the application. This collected data is then processed at the IBM cloud-based server. Based on that, application metrics' reports are sent from the analytical server to the KPI visualization system. In addition, several network metrics' reports are collected from the 5G self-contained node and visualized on the KPI-VS. IBM testbed administrator can also access KPI reports in a visual format from the KPI visualization system through a web-based API.

Finally, the third step of information sequence is devoted to stop running experiments. In this respect, a stop experiment message is sent from the IBM cloud-based server to the 5G self-contained node and a notification is relayed to the KPI visualization system. This notifies the KPI visualization system with the end of running experiments and also causes killing of running applications and leads the 5G self-contained node to offloading network slices.

5.3.3.5 *Planned KPIs to be tested*

The complete set of the initial UC3.4 technical and business KPIs are defined in the deliverable D1.1A (Section 5.3.4.3). Nevertheless, in Cycle 1 deployment, we place emphasis on the fact that our aim is to adopt a stepwise approach towards both service/infrastructure deployment and KPIs measurement, in order to align the testbed, IBM cloud-based server, and KPI visualization system implementations. In this regard, the initial iterations during Cycle 1 allowed us to perform an initial validation of some network KPIs, with the goal of improving them and enhancing the end-to-end system performance. Throughout the subsequent cycles, we will perform a more critical validation to draw up recommendations that will be documented and disseminated. Business KPIs are particularly investigated in Cycle 2 and 3, whereas critical technical KPIs that are not met or verified in Cycle 1 will be paid most attention in Cycle 2 and 3. For completeness, the complete set of expected technical KPIs is presented in Table 30 and Table 31 below.

Table 30: UC3.4_SC1 Technical KPIs

Technical KPIs			
KPI	**Target**	**Measurement method/formula**	**Justification**
Positioning accuracy	< 1m	Compare calculated position with actual location	– for enhanced predictive maintenance of IoT devices – help the operation team to know the exact position of massive number of IoT devices – help in mobile scenarios, e.g., asset tracking and indoor aerial vehicles
Coverage	> 99.9%	Data reception success rate when device in different locations (statistical sampling from >1000 measurements in different locations)	– IoT sensors need to be covered with high probability to allow real-time monitoring of device status and anomaly measurement – useful for mobile scenarios towards a seamless handover and less service disruption
Reliability	best effort	% of data delivered without data corruption	

Connection density	> 1	Evaluate service while increasing device density	– massive IoT: large number of IoTs deployed around campus
Projection of battery life	number of years	How many years it can prolong (e.g., how long it will last)	– the benefits of using 5G technology as compared to other technologies to achieve longer battery life
Energy reduction	%	% of energy reduction when choosing the best power saving mode	– the benefits of using 5G technology and power saving modes to reduce energy consumption

Table 31: UC3.4_SC2 Enhanced safety monitoring and object detection technical KPIs

Technical KPIs			
KPI	**Target**	**Measurement method/formula**	**Justification**
Coverage	> 99.9%	Data reception success rate when device in different locations (statistical sampling from >1000 measurements in different locations)	– prevent service disruption if the cameras are deployed at different locations covered by the cell – help in mobile scenarios, e.g., indoor aerial surveillance
Reliability	> 99.99%	% of data delivered without data corruption	– wireless networks must reliably transmit large amounts of data at very high speeds to ensure no degradation in quality of videos – reliability for less blurry video streaming at high frame per second (fps) and frame refresh rate (frr)
Data Rate	> 100Mbps (per cell)	Throughput measurement at device	– average uplink rate per camera is 25 Mbps, and for 4 cameras, it yields 100 Mbps
Latency	< 10ms	Network + elaboration latency in normal operation mode	– stringent delay requirements for seamless real-time surveillance and monitoring, especially for anomaly detection and emergency situations

As a result of the field trials and test executions in Cycle 1, the table below presents the achievable set of the network KPIs from the eMBB network slice when the base station operates in the 5G SA mode.

Table 32: UC3.4_network KPIs measured in Cycle 1

KPI	Target	Measurement method	Measured Value (5G – SA mode)
Downlink rate	> 300 Mbps	Using iperf protocol where the base station is configured as a client and the 5G UE as iperf server	290 Mbps
Uplink rate	> 100 Mbps	Using iperf protocol where the base station is configured as server and the 5G UE as iperf client	42 Mbps

Network latency	< 10 ms	Network + elaboration latency in normal operation mode	22.5 ms

Finally, the set of targeted business KPIs is given in Table 33 below.

Table 33: UC3.4 Business KPIs

Business KPIs	
KPI	**Target & Measurement method/formula**
Cost for operations, repair & maintenance of IoT infrastructure	Better than conventional system. IoT devices to have 5+ years of battery life
Time to respond to detect any potential device issues	**Note:** Target values and measurements methods are under investigation
Health and safety of a repairman	
Improved maintenance staff experience	Survey: e.g., based on the satisfaction of maintenance team
Improved occupant experience	Survey: e.g., based on presence sensors' efficiency, HVAC smart sensors, physical security enhancement
Building maintenance cost	e.g., by 10-20%
Physical security improvement	e.g., based on number of detected incidents by operator vs camera
Cost saving	by choosing proper power saving modes, cost of charging and replacing IoT devices would be decreased

5.3.3.6 *Test cases and scenarios definition*

In order to measure the envisaged technical and business KPIs, the respective test scenarios, test areas, and test cases are defined according to the T1.4 methodology. First, test scenarios define adequate environmental conditions to test the intended application and network KPIs. Second, test areas show the UC3.4 architecture broken down into various areas of focus in order to determine test levels before end-to-end integration. These test areas address: unit/component test and integration, site integration and end-to-end integration. Finally, the test case matrix quantifies the test cases based on the underlying test areas, scenarios, test objectives and vertical KPIs. In the table below, U-SC and N-SC refer respectively to the application and network levels of the underlying scenario.

Table 34: UC3.4 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC3.4_PRE	Pre-trial unit and integration test		A default scenario for pre E2E testing	To carry out all the necessary unit and integration testing before E2E can start
UC3.4_SC1_1	Scenario-A- Stage 1: Cooperative Positioning and Predictive	U-SC	Scenario-A- Stage 1: multiple IoT devices deployed in	Verifying the capability of 5G networks to accurately locate 5G-enabled IoT devices in an indoor

	maintenance		IBM Campus connected to 5G BS	environment
UC3.4_SC1_2	Scenario-A- Stage 2: Cooperative Positioning and Predictive maintenance	U-SC	Scenario-A- Stage 2: multiple IoT devices deployed in IBM Campus connected to 5G BS	To know the current status of 5G-connected IoT devices and predict their respective future operation
UC3.4_SC2	Scenario-B: Enhanced safety monitoring and object detection	U-SC	Scenario-B: multiple IoT devices deployed in IBM Campus connected to 5G base station	To use 5G network to consistently receive UHD video streaming, thereby enabling applications such as video object detection, and anomaly detection
NC3.4-SC1	Standard mMTC network slice	N-SC	The use of pre-loaded mMTC network slice on 5G base station in Cycle 1. Onboarding network slice to the base station by NOKIA CDSO (Cycles 2 and 3)	Testing the uplink and downlink capacity of the respective network slice when transmitting IoT sensors' data over standard mMTC network slice
NC3.4-SC2	Standard eMBB network slice	N-SC	The use of pre-loaded eMBB network slice on 5G base station in Cycle 1. Onboarding network slice to the base station by NOKIA CDSO (Cycles 2 and 3)	Testing the uplink and downlink capacity of the respective network slice when enabling video streaming over standard eMBB network slice

In the test areas table below, test areas 1 to 5 are in the scope of Cycle 1 field trials.

Table 35: UC3.4 test areas

TA ID	Test Area	Test Level	Description	Cycle 1 Scope
UC3.4_TA_1	IBM Testbed - 5G self-contained	Unit Test	Installation of the 5G self-contained node in	Installed as part of Cycle 1 scope

	node		IBM Campus	
UC3.4_TA_2	IBM Testbed - 4K cameras, and IoT devices installation	Unit Test	Deploying IoT devices and 4K cameras in IBM Campus	Deployed as part of Cycle 1 scope
UC3.4_TA_3	IBM Testbed - IBM custom-made analytical server	Component Test	Building a custom-made analytical server on the IBM cloud to perform analytic and ML algorithms	Built as part of Cycle 1 scope
UC3.4_TA_4	IBM Testbed - IBM analytical server (cloud application/ machine learning)	Integration Test & (E2E Test)	Carrying out the integration between IBM Testbed and the IBM custom-made analytical server via APIs available from the 5G base station and IoT devices	Carried out as part of Cycle 1 scope
UC3.4_TA_5	IBM Testbed – KPI-VS	Integration Test & E2E Test	Carrying out the integration between IBM Testbed and the KPI-VS through REST APIs provided by the KPI-VS side	Carried out as part of Cycle 1 scope
UC3.4_TA_6	IBM Testbed orchestration via NOKIA CDSO	Integration Test	Integration between the 5G base station and NOKIA CDSO for UC3.4 Orchestration	Cycle 2
UC3.4_TA_7	E2E Use Case	E2E Test	E2E integration, orchestration of UC3.4, connection to the visualization system, slice establishment (mMTC slice and eMBB), E2E connectivity, E2E KPIs measurement	Cycle 2 and Cycle 3

In the test case matrix below, please note that each test case is a result of mapping a specific scenario and test objectives onto an underlying test area. For instance, Test Case 4 (TC04) below represents the mapping of application-level Scenario-A- Stage 1 (UC3.4_SC1_1) (i.e., cooperative positioning and predictive maintenance for smart industrial IoT system) and network level scenario (NC3.4-SC1), i.e., mMTC network slice, into Test Area 4 (UC3.4_TA_4). In Test Area 4, the IBM 5G node will be integrated with the IBM cloud-based server.

The order of importance for technical KPIs during Cycle 1 is given in the test case matrix, e.g., coverage is the 1st technical KPI for TC04 to TC07 during Cycle 1. In addition, the tick boxes in the test case matrix below refer to that the corresponding KPIs are of interest of the respective test cases, but their respective preference (i.e., order of importance) will be determined in the subsequent cycles. It is worth mentioning that TC01, TC02, and TC03 are completed in Cycle 1 trials. In addition, TC04 to TC07 are started in Cycle 1 and will be completed in the subsequent cycles, i.e., Cycles 2 and 3. Finally, TC08 to TC11 will be started in Cycle 2.

Table 36: UC3.4 TC01-TC07 TCs Matrix

	TC01	**TC02**	**TC03**	**TC04**	**TC05**	**TC06**	**TC07**
Test Areas	UC3.4-TA1	UC3.4-TA2	UC3.4-TA3	UC3.4-TA4	UC3.4-TA4	UC3.4-TA5	UC3.4-TA5
Target Vertical KPIs - Primary & Secondary							
Positioning accuracy							
Coverage				1st	1st	1st	1st
Reliability				2nd	2nd	2nd	2nd
Connection density				3rd		3rd	
Data Rate					3rd		3rd
Latency					4th		4th
Projection of battery life				4th		4th	
Energy reduction				5th		5th	
Scenario ID							
UC3.4-PRE	X	X	X	X	X	X	X
UC3.4-SC1_1							
UC3.4-SC1_2				X		X	
UC3.4-SC2					X		X
NC3.4-SC1				X		X	
NC3.4-SC2					X		X
NC3.4-SC3							

Table 37: TC08-TC11 TCs Matrix

	TC08	**TC09**	**TC10**	**TC11**
Test Areas	UC3.4-TA6	UC3.4-TA7	UC3.4-TA7	UC3.4-TA7
Target Vertical KPIs - Primary & Secondary				
Positioning accuracy		X	X	
Coverage			X	X
Reliability			X	X
Connection density			X	
Data Rate				X
Latency				X
Projection of battery life			X	
Energy reduction			X	
Target Vertical KPIs				

Time to response to detect any potential device issues			X	
Cost for repair & maintenance			X	
Improved maintenance staff experience			X	
Physical security improvement				X
Improved occupant experience			X	X
Scenario ID				
UC3.4-PRE	X			
UC3.4-SC1_1		X		
UC3.4-SC1_2			X	
UC3.4-SC2				X
NC3.4-SC1		X	X	
NC3.4-SC2				X
NC3.4-SC3		X		

5.3.3.7 *Trials planning*

Figure 60 below shows the Gantt chart for UC3.4 during Cycle 1. As previously stated, test cases TC01 to TC03 are completed in cycle 1 while TC04 to TC07 started in Cycle 1 and will be completed in Cycle 2. In addition, test cases TC08 to TC11 are in the scope of the subsequent cycles, namely, Cycle 2 and Cycle 3. Please note that each test case is a result of mapping a specific scenario into an underlying test area. For a detailed explanation of the concept of test area, please refer to the explanation in Section 5.3.4.5.

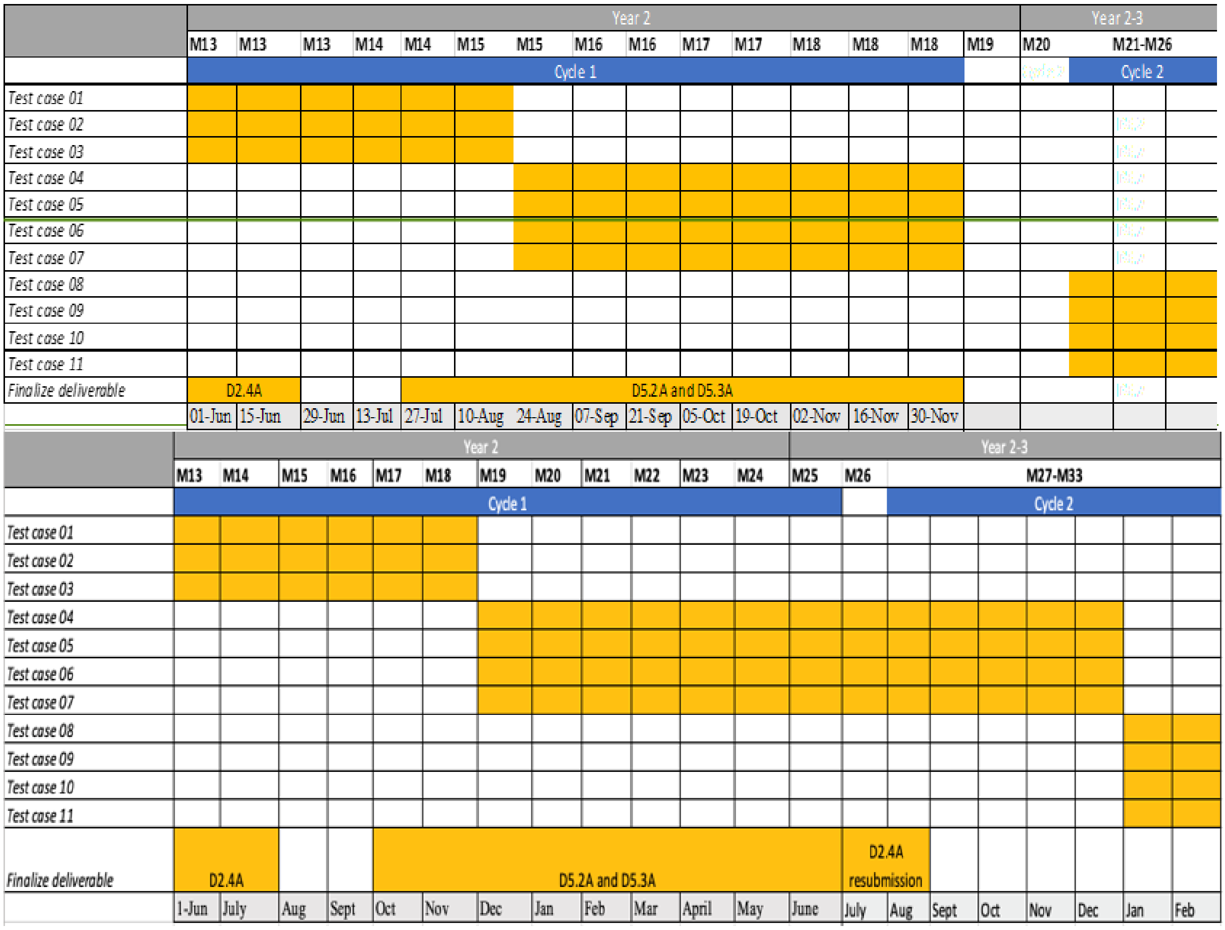

Figure 60: UC3.4 Gantt chart

5.3.3.8 *Lessons learned from the deployment phase*

The main learned lessons from the deployment phase in Cycle 1 are as follows:

- To successfully attach the IoT devices to the base station, we needed to use IoT devices that operate in the same supported bands as the same station and the same modes supported by the base station (e.g., NB-IoT and LTE-M).
- For the base station to meet the required data rate in the uplink, we needed to adopt the TDD mode and allocate more time slots for the uplink direction at the cost of decreasing the maximum achievable downlink data rate.
- For the integration with the KPI-VS, a websocket to REST-API script is developed to collect the KPIs from the base station (websocket) and send them to the KPI-VS (REST-API).

In Cycle 2, we will focus on the key technical challenges encountered in Cycle 1 and shed light on the parts that did not work as well as planned for Cycle 1. Such challenges will be aimed to addressed in the subsequent cycles.

5.3.4 UC3.5: Autonomous assets and logistics for smart harbour/port

5.3.4.1 *UC test objective and design*

Yara is an end user of the 5G system. Key issues for Yara are real time capability, availability and high cyber security capability (it needs to be secure, not creating a backdoor into Yara's network). Yara also wants to understand the limitations of the 5G system to see future potential use of the network according to the need for taking advantage of the possibilities of Industry 4.0.

To achieve high availability for the end users, the 5G system needs to provide coverage download and upload speeds, latency demands and roaming within the area where this is needed, such that the equipment can perform the function needed. To understand the technology tests means also to understand the limits of the 5G system. To obtain availability, there need to be APIs assisting the end user to perform problem solving within the network e.g., is it the 5G device or the 5G system that is causing the problem.

To achieve real time capability, the system needs to react quickly in a predictable way. This means that the latency needs to be low and repeatable. This might give the need of slicing to guarantee performance when the network is loaded and capacity need to be shared with other traffic.

The system needs to be secure. It also needs to be transparent for the end user to be able to verify that it is secure to be able to trust the system.

The test design is planned to understand if a 5G system is able to achieve the functionality needed for the end users. So, in the design there will be implemented a 5G node that is connected to the 5G VINNI and 5G devices and test equipment will be used at site to verify the system. This use case did not participate in cycle 1 trials, nevertheless the planning will contribute to the cycle 2 planning.

The complete test setup including Yara's contribution to the UC3.5 is indicated in the Figure 61:

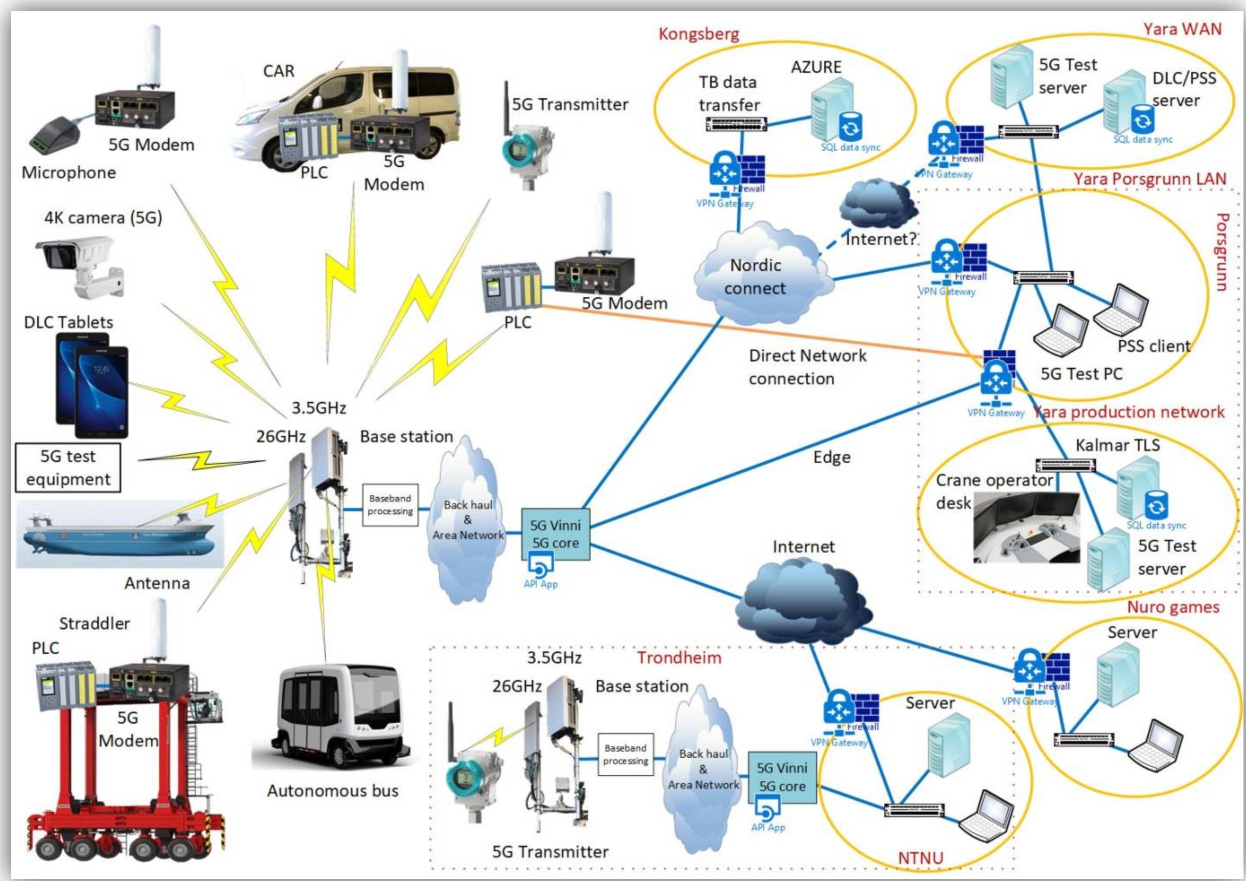

Figure 61: The complete test setup including Yara's contribution to the UC1.5 and UC3.5

5.3.4.2 *Test planning*

Table 38: UC3.5 Test planning

Activity	May	June	July	August	September	October	November
Telenor execute test of commersial 5G							
Ship testequipment to site							
Yara to perform tests on commersial 5G							
Connect 5G system to Vinni							
Telenor to perform tests with 5G Vinni							
Yara to perform tests with 5G Vinni							

5.3.4.3 *Architecture and information flow*

The UC3.5 consists of three different business scenarios that together is the Smart port. The first scenario is called 3.5.1 DLC (Digital Lean Container). In this scenario, we will investigate the usability to use tablets that update information in a datacenter hosted server system. The topology for this use case is shown in Figure 62.

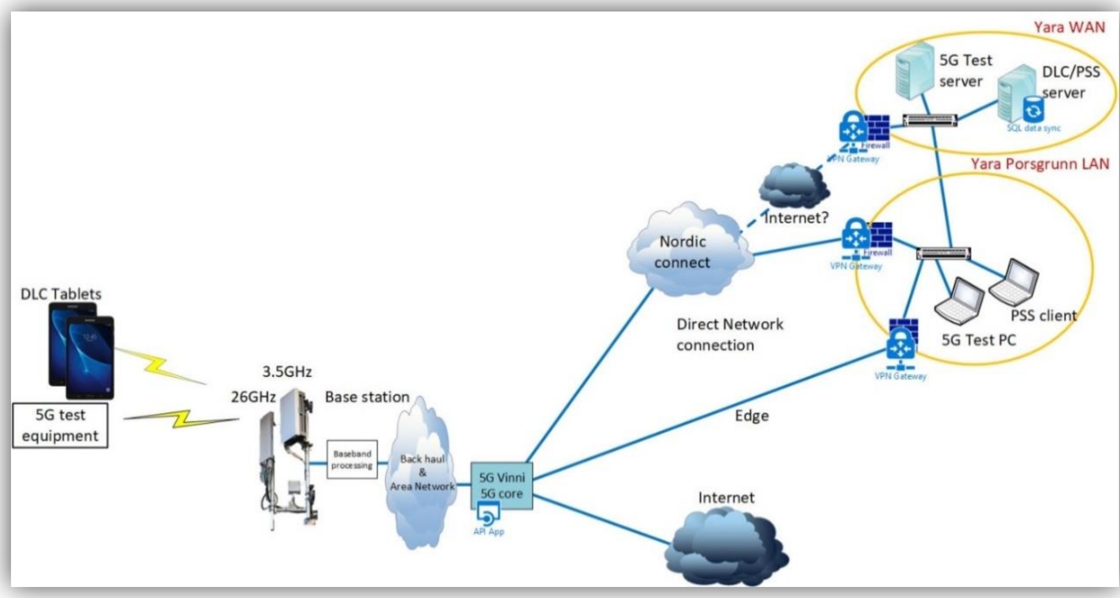

Figure 62: The UC3.5 Architecture

The next scenario is called 3.5.2 Autonomy. In this scenario, we will test if the 5G system is capable to support autonomy. It will first start easy with performance checks and over time increase the complexity of the test and make it more and more similar to the needs of autonomy. This scenario will need a local connection to the Yara Porsgrunn network to reduce the overall latency of the system. The complete setup is shown in Figure 63.

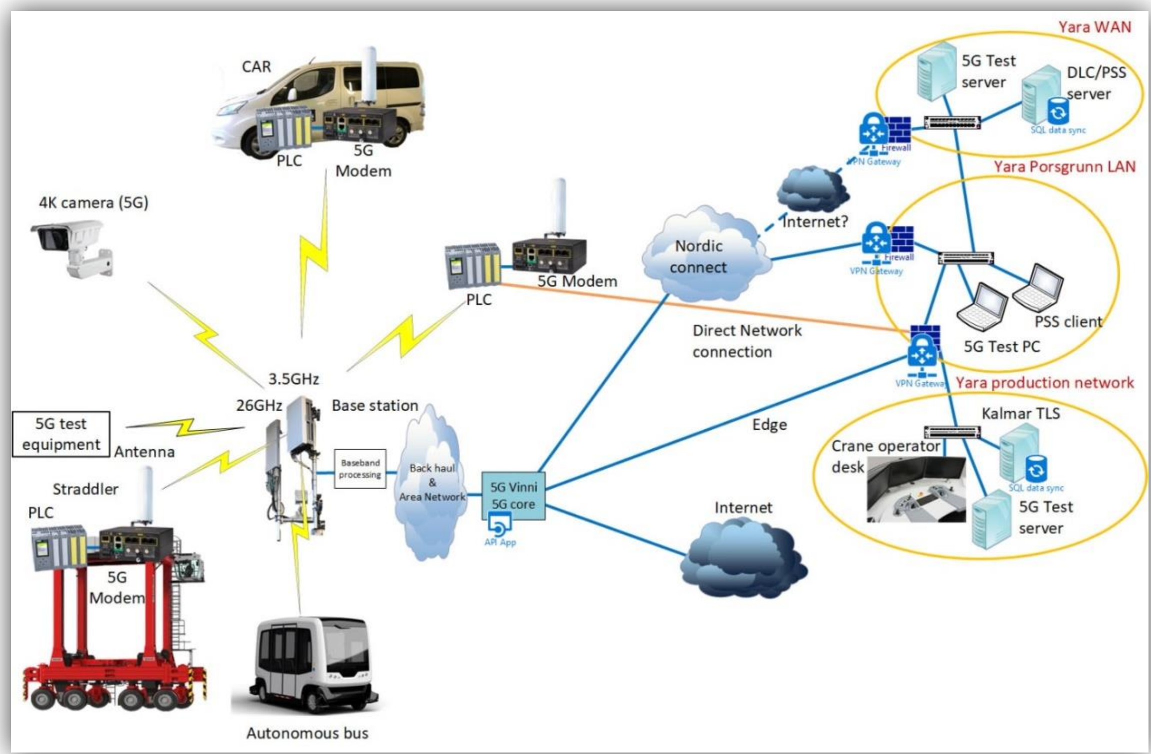

Figure 63: The Autonomy Scenario Setup

The last test is called 3.5.3 High speed data transfer. In this scenario we will investigate that the 26GHz part of the 5G system is capable to upload large files used for diagnostic to a cloud service. The relevant system is shown in the figure.

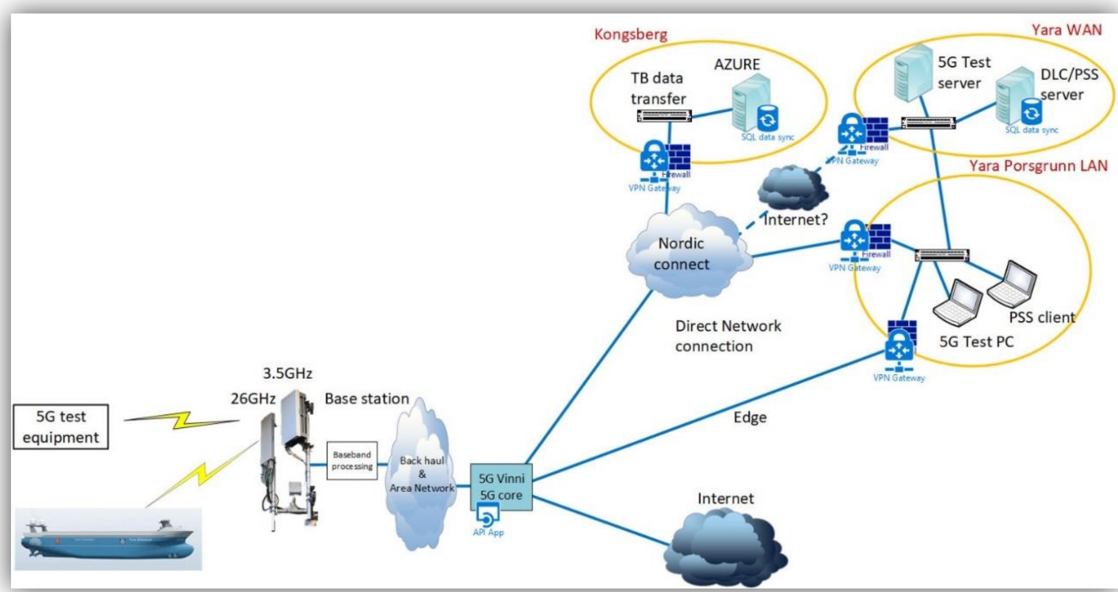

Figure 64: The High-Speed Data Transfer Scenario Setup

No need for orchestration is identified so far.

5.3.4.4 *Collaboration with the testbeds and deployment*

The overall testing set-up is illustrated in Figure 65. It consists of the following components:

- The Cross-Domain Service Orchestrator (CDSO)
  Controls (re-)configuration of the system to test, starts and stops tests, and notifies the KPI Visualization System about new results being available.
- The KPI Visualization System (KPI-VS)
  Retrieves measurement data from the results data base, analyses the data and presents the results.
- The Results Data Base
  For storing measurement results from the tests. The results are pushed to the database both from the TaaS and from the vertical's test set-up.
- The 5G-Vinni Testing as a Service system (TaaS)
  A system for performing tests within the 5G-Vinni virtualized network. It can also be used to perform KPI measurements by sending simulated traffic between so called Hawkeye end-points (virtual probes) that can be installed both inside and outside of the 5G-Vinni network.
- The vertical's application-based test set-up, consisting of
  - One or more servers generating application traffic
  - One or more PCs running software that controls the configuration of the tests, starts and stops the tests, and ensures that the measurement results are sent to the results data base. The PC(s) software can be remotely controlled by the CDSO or operated manually.
  - UEs or CPEs that communicate with the 5G network, and which are either connected to the test application server or located on an independent unit (e.g. a robot) sending and/or receiving data associated with e.g. sensors and actuators.

The test set-up will not be completely implemented for the tests in Cycle 1, this includes:

- The CDSO will not be used for test case automation. Instead, the tests will be conducted through manual procedures (e.g. for starting and stopping the tests).
- The measurement results from the vertical's application-based test set-up will not be automatically pushed to the results data base. This will instead be done manually.
- The integration between the 5G-Solutions KPI Visualization System and the 5G-Vinni TaaS system will only be partly implemented.

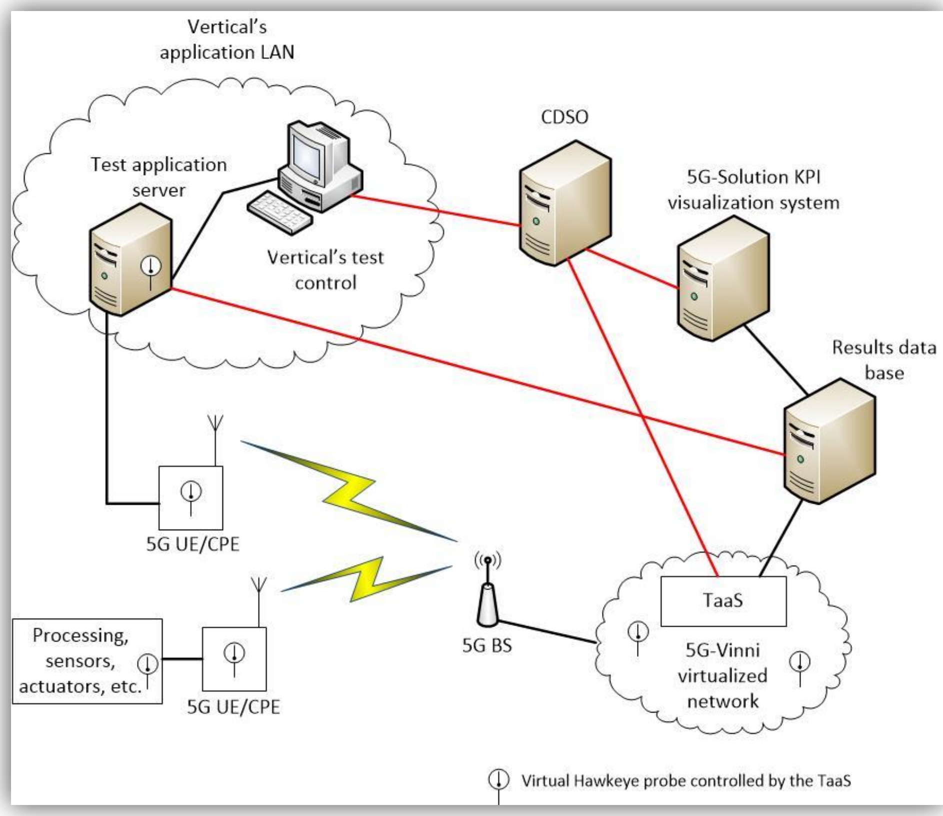

Figure 65: UC3.5 Overall Testing Setup

5.3.4.5 *In Figure 65 the black and red solid lines indicate message exchange between components. The message exchanges indicated by red solid lines will not be implemented in Cycle 1.Test cases*

Table 39: UC3.5 test scenarios

SC ID	Scenario Name	Scenario Type	Test Objective(s)
UC3.5-SC-01	Coverage outdoor	U-SC	The objective for this test is to investigate the practical coverage outdoor of a 5G system and to verify that the coverage is sufficient in the specified area.
UC3.5-SC-02	Coverage indoor	U-SC	The objective for this test is to investigate the practical coverage indoor of a 5G system and to verify that the coverage is sufficient in the specified building.
UC3.5-SC-03	Real-Time Capability/Usability	U-SC	The objective for this test is to investigate whether 5G is capable to be a part of a real time environment
UC3.5-SC-04	Data Transfer Rate	U-SC	The objective for this test is to investigate the practical 5G download and upload speeds and verify that it is suitable to use one or several 4k cameras
UC3.5-SC-05	Combinatory test indoors/outdoors	U-SC	The objective for this test is to investigate the practical 5G latency, download and upload speeds and verify that it is suitable to be used in

			real time applications
UC3.5-SC-06	Positioning	U-SC	The objective for this test is to investigate the positioning accuracy capability of a 5G system outdoor
UC3.5-SC-07	Moving target	U-SC	The objective for this test is to investigate the practical 5G latency, download and upload speeds and verify that it is suitable to be used in real time applications with moving targets
UC3.5-SC-08	High-speed connection (26.6 GHz)	U-SC	The objective for this test is to investigate the possible speed with the 26.6 GHz system and see the usability for the link to upload a large amount of data from the vessel
UC3.5-SC-09	Cyber Security	U-SC	The objective for this test is to investigate the cyber security capability of the 5G system
UC3.5-SC-10	Uptime	U-SC	The objective for this test is to investigate whether the uptime of a 5G device is adequate
UC3.5-SC-11	Data Quality	U-SC	The established commercial 5G structure must be finalized and connected to 5G VINNI. Test equipment have to be shipped to the site.
UC3.5-SC-12	Roaming 5G WiFi	U-SC	The objective for this test is to investigate the data quality during transfer from a 5G system to a WiFi system.
UC3.5-SC-13	Log analysis	U-SC	The objective for this test is to investigate the quality of the logs from a 5G system to assist the end user in problem solving.
UC3.5-SC-14	Narrow band	U-SC	The objective for this test is to investigate that the 5G narrow band is suitable for IIOT devices and gives possibility of log battery life. It has to be robust to normal disturbances
UC3.5-SC-15	AR usability	U-SC	The objective for this test is to investigate whether the 5G system gives a good experience for using AR in the maintenance support
UC3.5-SC-16	Autonomous Bus	U-SC	The objective for this test is to investigate the practical 5G latency, download and upload speeds and verify that it is suitable to be used in real time applications with an autonomous bus
UC3.5-SC17	Sound testing	U-SC	The objective for this test is to investigate to see if it's possible to connect a 5G device on site that can be used as input to an analysis performed in a cloud computer (Nuro games) to search for abnormalities

Table 40: UC3.5 test areas

TA ID	Test Area	Test Level
UC3.5-TA-1	5G test equipment to Yara WAN	E2E
UC3.5-TA-2	5G test equipment to Yara LAN	E2E
UC3.5-TA-3	5G test equipment to Yara Production network	E2E

UC3.5-TA-4	5G test equipment to Cloud services	E2E

Table 41: UC3.5 TC01-TC09 TCs Matrix

	TC01	TC02	TC03	TC04	TC05	TC06	TC07	TC08	TC09
Test Areas	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3 UC1.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA4	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3 UC3.5-TA4 UC3.6-TA1 UC1.5-TA1
Target Vertical KPIs - Primary & Secondary									
Coverage	1st	1st			2nd		3rd	2nd	
Download speed				1st	3rd		4th	1st	
Upload speed				2nd	4th		5th		
Latency			1st		1st		1st		
Speed (moving) of user equipment							2nd		
Positioning accurancy						1st			
Cyber security									1st
Data Quality									
Quality of logs									
Scenario ID									
UC3.5-SC1	X								
UC3.5-SC2		X							
UC3.5-SC3			X						
UC3.5-SC4				X					
UC3.5-SC5					X				
UC3.5-SC6						X			
UC3.5-SC7							X		
UC3.5-SC8								X	
UC3.5-SC9									X

Table 42: UC3.5 TC10-TC17 TCs Matrix

	TC10	TC11	TC12	TC13	TC14	TC15	TC16	TC17
Test Areas	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3 UC3.5-TA4 UC3.6-TA1 UC1.5-TA1	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3 UC3.5-TA4 UC3.6-TA1 UC1.5-TA1	UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3	UC3.5-TA1 UC3.5-TA2 UC3.5-TA3 UC3.5-TA4 UC3.6-TA1 UC1.5-TA1
Target Vertical KPIs - Primary & Secondary								
Coverage	1st	2nd	2nd		1st	3rd	1st	
Download speed						1st	3rd	
Upload speed						2nd	4th	
Latency	2nd						2nd	
Speed (moving) of user equipment								
Positioning accuracy								1st
Cyber security		1st					5th	
Data Quality			1st		2nd			
Quality of logs				1st				
Scenario ID								
UC3.5-SC10	X							
UC3.5-SC11		X						
UC3.5-SC12			X					
UC3.5-SC13				X				
UC3.5-SC14					X			
UC3.5-SC15						X		
UC3.5-SC16							X	
UC3.5-								X

SC17								

5.3.4.6 *Planned KPIs to be tested*

Table 43: UC3.5Planned KPIs to be tested

KPI	Reference	Method
Download link data (Mbps)	>100	Measurement
Upload link data (Mbps)	>100	Measurement
Latency (ms)	<10	Measurement with reference
Density (devices/ m^2)	>1	
Reliability (%)	>99.99	Measurement / Statistical
Position accuracy (m)	<0.5	Measurement with reference
Coverage (%)	>99.9	Measurement
Mobility (km/h)	<50	
Availability (%)	>99.99	Measurement / Statistical

5.4 LL4: Media & Entertainment

5.4.1 UC4.1: Ultra High-Fidelity Media

5.4.1.1 Cycle 1: 1st end to end trial

5.4.1.1.1 UC test objective and design

The main challenge which broadcasters currently face is the understanding of advantages, e.g., additional capabilities such as slicing, or limitations that emerging NGA networks (with focus on 5G) bring, in order to take advantage and adapt technological infrastructures and business models. To this end, regardless of whether content mobile distribution services exist over 4G mobile networks, they cannot guarantee higher quality and eventually support lower content formats in most cases.

In order to test the potential of distributing UHFM over emerging 5G networks, FNET will provide content and services to the 5G-SOLUTIONS UOP 5G-VINNI testbed. In addition, FNET will define a set of comprehensive scenarios able to provide meaningful outcomes to analyze technological, application and business aspects. Specifically, these scenarios will concern streaming content services provided by FNET in various formats to available 5G devices using UOP 5G-VINNI testbed.

Cycle 1 focus for UC4.1 will be:

- the deployment and the end-to-end setup,
- VNFs implementation,
- integration with the orchestrator and visualization system and
- measurement of the Latency and Throughput KPIs

This use case will be performed during cycle 1 trials.

5.4.1.1.2 Test planning

In order to deploy the test equipment and application as well as to develop the necessary VNFs/PNFs early planning was made in collaboration with FNET transmission engineers, UoP testbed, CDSO and Visualization system representatives.

Planning activities sequence is illustrated in Figure 66.

	Phase 2						Cycle 1 trials							
	Dec 2019	Jan 2020	Feb 2020	Mar 2020	Apr 2020	May 2020	Jun 2020	Jul 2020	Sep 2020	...	Jan 2021	...	May 2021	June 2021
High level architecture definition														
Detailed architecture definition including UOP deployment planning as well connectivity to CDSO and VS														
FNET lab deployment and connection establishement to UOP and VS														
Start streaming tests														
UC deployment and 1st version of VNF implementation														
1st end to end trials w/o CDSO														
Second VNF version implmemantation														
2nd trial incl. CDSO (VS was not connected to UOP)														
Interim trials														
Designing ZTA adoption based on Cycle 1 UC4.1 deployment														
MLL between UC4.1 and UC4.4 planning														
MLL UC4.1 and UC4.4 trials														

Figure 66: UC4.1 Test Deployment Planning Sequence

5.4.1.1.3 UC Architecture

The high-level architecture of the UC4.1 is illustrated in Figure 67.

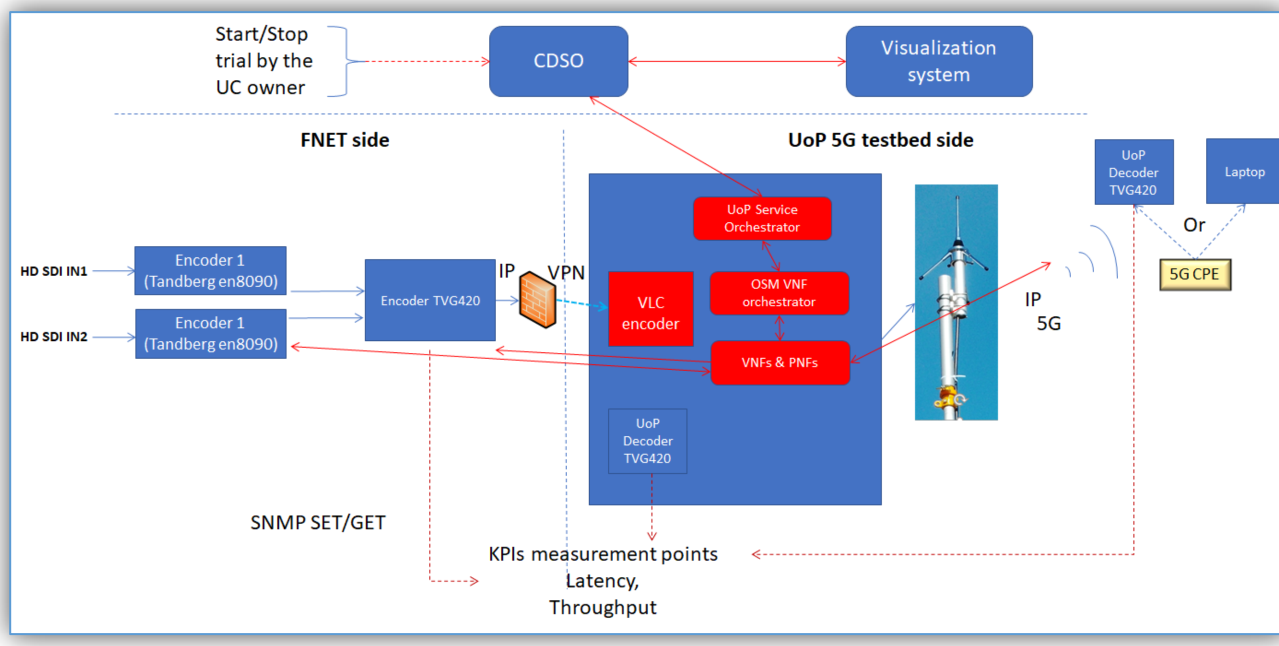

Figure 67: UC4.1 High level architecture

Three encoders are deployed in FNET premises in Athens able to stream content in multiple speeds. The Tandberg encoders stream the signal while the TVG420 encoder is used to multiplex the signals and create a demand for higher throughput.

The signal is streamed via public internet to UoP 5G testbed in Patras.

At UoP premises, two TVG420 decoders are deployed: the first one is deployed at the "entrance" of the core network while the second one at the signal reception site (using UoP 5G radio). In this way end-to-end application latency will be measured excluding the impact of the public network.

All measurements will be done via SMNP requests from the visualization system to the TVG420 encoders and decoders.

In addition, a VLC encoder will be deployed in UoP enabling the user to subscribe to an IP address and request the stream.

A VNF will be implemented able to initiate, terminate and modify the stream speed. The VNF will be onboarded to the UoP OSM orchestrator. It is envisaged that UC4.1 will use CDSO. The respective flow is described in detail in section 5.4.1.1.5.

At the reception side two types of tests will be performed:

- Using the TVG420 decoder, latency and throughput can be measured.
- Using a 5G mobile device, with a VLC player installed, user experience can be evaluated.

5.4.1.1.4 Information sequence diagram

In order to define test scenarios and entities involved, a high-level flow diagram was defined as presented in Figure 68. Such information flow defines the envisaged end state when all components will be integrated. A stepwise approach will be followed to deploy the equipment, perform connections and test the end-to-end service.

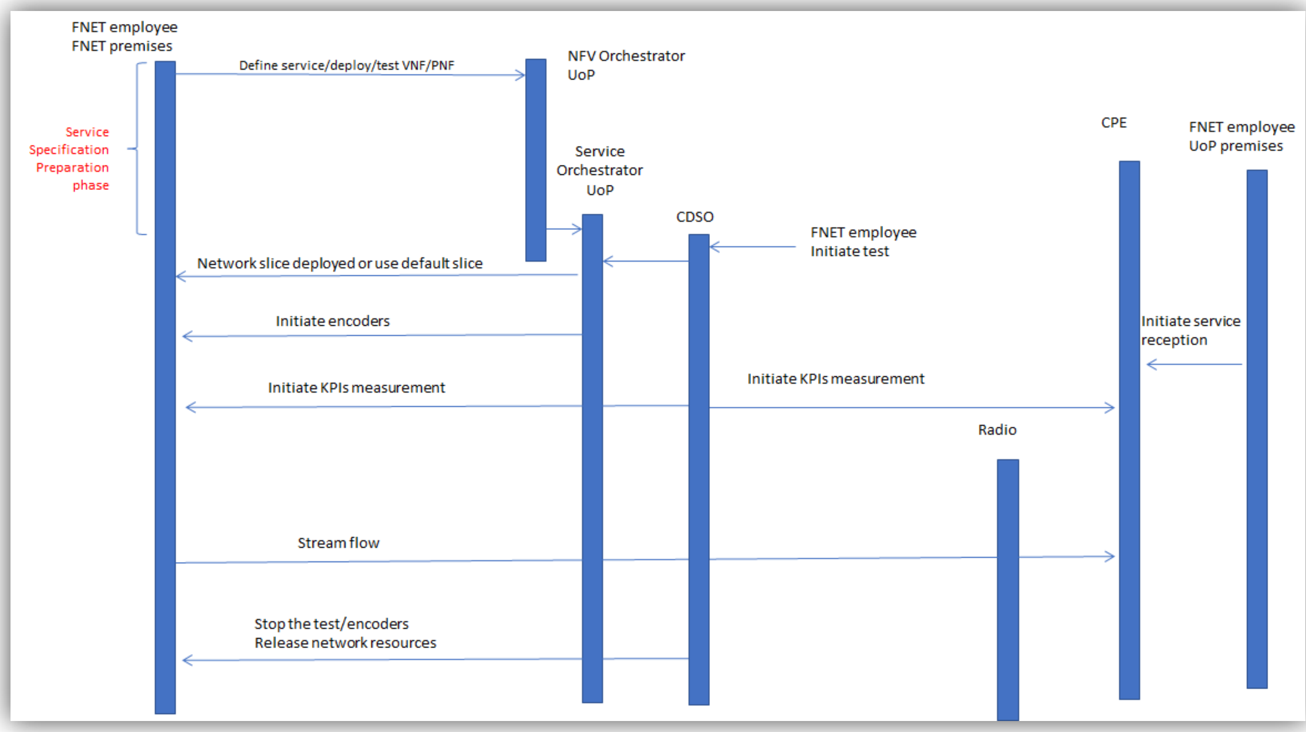

Figure 68: UC4.1 High level information flow diagram

5.4.1.1.5 Orchestration Flow

The following flow assumes that the end-to-end infrastructure is established:

Table 44: UC4.1 Orchestration Flow

	Step	Interface with	Comments
1 User activates experiment UI/API to CDSO			
1.1	UC owner starts the trial	CDSO	The CDSO provides the interface to the UC owner to provide information about the slice parameters and

			the video stream activation. If needed, separate order will be given by the UC owner to configure the slide and activate the streaming.
1.2	Create connection from CDSO to UoP & Authenticate	UoP Orchestrator	Facility site is on https://patras5g.eu/
1.3	Activate encoders 2x Tandberg en8090, TVG420. In addition, at a later time, a TVG420 decoder in UoP premises will be activated	No interface to orchestrator. The process is managed by the UoP service orchestrator.	Equipment: Encoders in FNET premises, Decoder in UoP premises Note: A VLC encoder is also installed in UoP premises. This will be continuously operational and there is no need to be orchestrated. If needed, a VNF will be implemented to control the VLC encoder as well. Process: The UoP services orchestrator will request from the OSM VNF orchestrator to activate the respective VNF. Either one VNF per equipment or one VNF addressing all equipment will be implemented. Within the VNF the appropriate SMNP[20] calls will be made towards the respective equipment (e.g., start, stop, etc.)
1.4	Activate Video Stream	No interface to orchestrator. The process is managed by the UoP service orchestrator.	This process is activated by the VNFs
1.5	Visualisation system activation, test start	Visualisation system, UoP Orchestrator	When VNFs are activated, according to the previous process, the UoP service orchestrator informs CDSO that the infrastructure is set up. Then the CDSO informs the visualization system that it should start measuring the KPIs.
2 Ongoing Status			
2.1	Get streaming equipment status	UoP Orchestrator	Show status. The VNFs will get the equipment status. This information will be given to CDSO through the UoP service orchestrator.
3 User Terminates Experiment UI/API to CDSO			
3.1	UC owner stops the trial	CDSO	The CDSO provides the interface to the UC owner to provide information in order to stop the trial.
3.2	Terminate Video Stream	UoP orchestrator	Then CDSO informs the UoP service orchestrator to terminate the streaming. The UoP services orchestrator sends the command to the OSM VNF orchestrator and the respective VNFs. The VNFs send the stop command to the equipment.
3.3	Terminate KPIs measurement	Visualisation system	When the trial is completed the UC owner will inform CDSO through the interface provided by CDSO. Then

[20] https://tools.ietf.org/html/rfc1157

			CDSO informs the visualization system to stop measuring the KPIs.

5.4.1.1.6 Planned KPIs to be tested

The complete set of the initial UC4.1 KPIs are defined in deliverable D1.1A (section 5.4.1.3.2).

Nevertheless, in Cycle 1 deployment we aim to adopt a stepwise approach towards both service/infrastructure deployment and KPIs measurement in order to align the testbed, CDSO and visualization system implementations. Target KPIs for Cycle 1 trials will be at least the ones referred in Table 45.

Table 45: UC4.1 Planned KPIs to be tested

KPI	Target	Measurement method/formula
Latency	< 5 ms (Live-TV distribution)	Measure latency
Throughput per 4K video stream	~15 Mbps	Measure throughput per device

5.4.1.1.7 Test cases and scenarios definition

In order to measure the envisaged KPIs, respective test scenarios and test cases are defined according to the T1.4 methodology. Such scenarios aim at defining adequate environmental conditions to test the intended KPIs.

Such scenarios are defined below:

Table 46: UC4.1 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC4.1-PRE	Pre-trial unit and integration test	N-SC	A default scenario for pre E2E testing	To carry out all the necessary unit and integration testing before E2E can start
UC4.1-SC1	Scenario-B: Live feed with 1 stream	N-SC	Scenario-B: Live feed with 1 stream (bandwidth range from 15 to 25Mbps)	Evaluate network management strategies. Evaluate unicast distribution of TV services under SLA.
UC4.1-SC2	Scenario-C: Live feed with 2 streams	N-SC	Scenario-C: Live feed with 2 streams (bandwidth range from 15 to 25Mbps)	Evaluate network management strategies. Evaluate unicast distribution of TV services under SLA.
NC4.1-SC1	Scenario NEM media slice	N-SC	Could be a network scenario that could be described	Evaluate network management strategies. Evaluate unicast distribution of TV services under SLA.
NC4.1-SC2	Scenario Other media slice 1	N-SC	Could be a network scenario that could be described	Evaluate network management strategies. Evaluate unicast distribution of TV services under SLA.

Table 47: UC4.1 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC4.1-TA1	FNET Side - encoders installation	Unit, Component Test	Installation of the streaming encoders	To test the streaming source infrastructure
UC4.1-TA2	FNET Side - Visualization system	Integration Test	Integration through the VPN with the visualization system and provision of the required SNMP MIPS.	To test the visualization system capability to access the encoder logs.
UC4.1-TA3	FNET Side-UoP testbed	Integration & E2E Test	Install decoder in UoP testbed and test E2E streaming.	To test the capability to stream from the FNET installation to a decoder accessing the UoP 5G-VINNI radio. The slide will be setup manually (NEM MEDIA slice)
UC4.1-TA4	FNET Side-UoP orchestrator	Integration & E2E Test	Create and install PNFs and integrate with the UoP network orchestrator	To test the E2E orchestration with the UoP orchestrator (OSM/FlowOne)
UC4.1-TA5	CDSO-UoP orchestrator	Integration Test	Integrate CDSO with UoP facility orchestrator	To test the service management through CDSO
UC4.1-TA6	E2E Use Case	E2E Test	E2E integration, onboarding (PNFs), orchestration, connection to the visualization system, slice establishment (NEM 5G media slice, other slices will be tested too), end2end connectivity, end2end KPIs measurement	To test different stream characteristics to measure the impact on the KPIs.

Table 48: UC4.1 TC01-TC06 test cases

	TC01	TC02	TC03	TC04	TC05	TC06
Test Areas	UC4.1-TA1	UC4.1-TA2	UC4.1-TA3	UC4.1-TA4	UC4.1-TA5	UC4.1-TA6
Target Vertical KPIs - Primary & Secondary						
Peak Data Rate				3rd	3rd	3rd
Latency				1st	1st	1st
Area traffic capacity						
Throughput per 4K video stream				2nd	2nd	2nd

Mobility						
Connection Density						
Media request response time						
Scenario ID						
UC4.1-PRE	x	x	x	x	x	
UC4.1-SC1						x
UC4.1-SC2				x	x	
NC4.1-SC1				x	x	x
NC4.1-SC2						

Table 49: UC4.1 TC06-TC08 test cases

	TC06	**TC07**	**TC08**
Test Areas	UC4.1-TA6	UC4.1-TA6	UC4.1-TA6
Target Vertical KPIs - Primary & Secondary			
Peak Data Rate	3rd	3rd	3rd
Latency	1st	1st	1st
Area traffic capacity			
Throughput per 4K video stream	2nd	2nd	2nd
Mobility			
Connection Density			
Media request response time			
Scenario ID			
UC4.1-PRE			
UC4.1-SC1		x	
UC4.1-SC2	x		x
NC4.1-SC1	x		
NC4.1-SC2		x	x

5.4.1.1.8 Lessons learned from the deployment phase

UC4.1 deployment has been impacted mainly by the fact that the 5G-VINNI testbed is still under development. To this end, close collaboration was necessary between FNET engineers and UoP responsible members towards a gradual deployment approach. Still, automation issues need to be resolved, e.g. guidelines for the VNF/PNF implementations, automating the trials using the OSM, the facility orchestrator and CDSO, etc.

Final decision on the slice(s) that will be used will be taken during the Cycle 1 trials period pending on the respective abilities of the testbed. The end-to-end UC4.1 trail will be achieved even without the existence of slice. As such facility service emerges; UC4.1 plan will be adapted accordingly to incorporate it.

5.4.1.2 *Trial 2: End to end trial with connection of the CDSO*

5.4.1.2.1 UC test objective and design

UC4.1 second end to end trial was performed on January 21st, 2021. This trial focused on the deployment and connection to the CDSO for the dynamic adjustment of the Encoders' data rate. Unlike Trial 1, TVG420 encoders and decoders KPIs were not measured in this trial, due to the absence of connectivity between the UoP testbed and the Visualization System. CDSO during the trial initiated the VNF, which thereafter, set the Data Rates at the Encoders.

5.4.1.2.2 Test planning

This test's planning was done after the time plan shown in Figure 66, as it was separate from the preparations for the 1st end to end trial. Again, in order to deploy the test equipment, an application planning was made in collaboration with FNET transmission engineers, UoP testbed, CDSO and Visualization system representatives.

5.4.1.2.3 UC Architecture

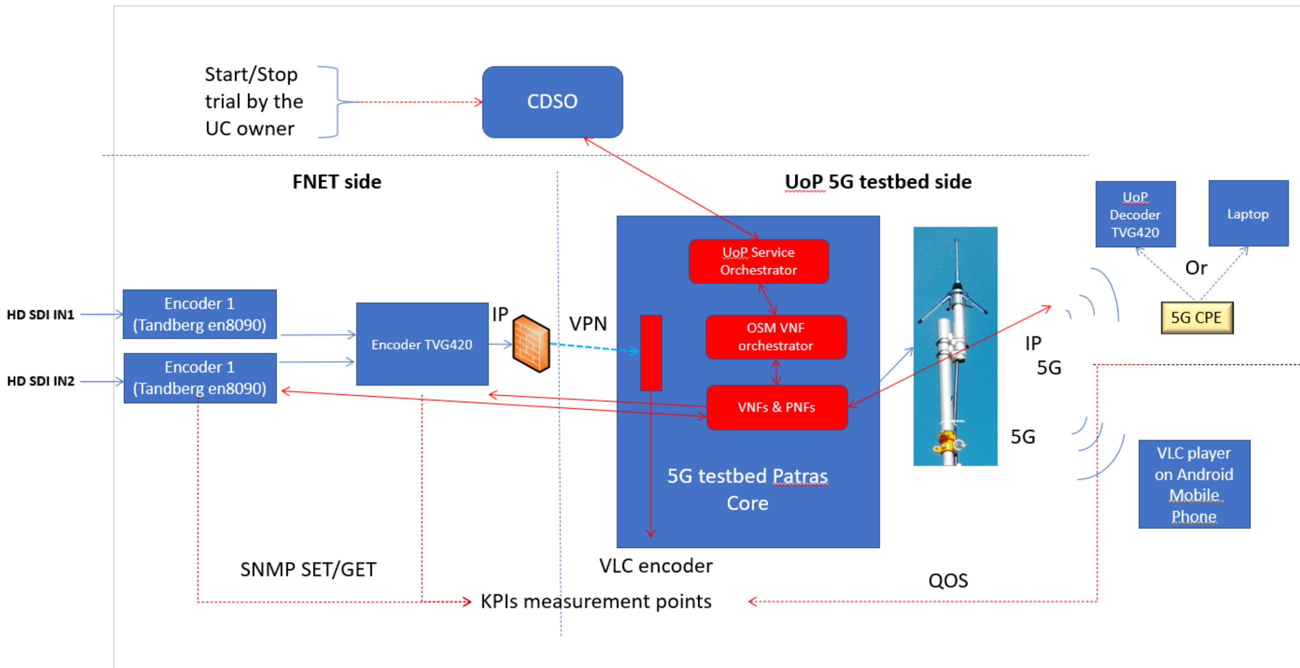

Figure 69: UC4.1 Cycle 1 trials architecture 2

Three encoders are deployed in FNET premises in Athens, able to stream content in multiple speeds. The Tandberg encoders stream the signal while the TVG420 encoder is used to multiplex the signals and create a demand for higher throughput.

The signal is streamed via public internet to UoP 5G testbed in Patras.

At UoP premises, two TVG420 decoders are deployed: the first one is deployed in the core network while the second one at the signal reception site (using UoP 5G radio). In this way end-to-end application latency will be measured excluding the impact of the public network.

CDSO connectivity has been implemented, able to initiate, terminate and modify the stream speed dynamically, without the use of the VNFs of Trial 1.

KPIs were not measured in this trial, due to the absence of connectivity between the UoP testbed and the Visualization System.

5.4.1.2.4 Information sequence diagram

In order to define test scenarios and entities involved, a high-level flow diagram was defined, as presented in Figure 70.

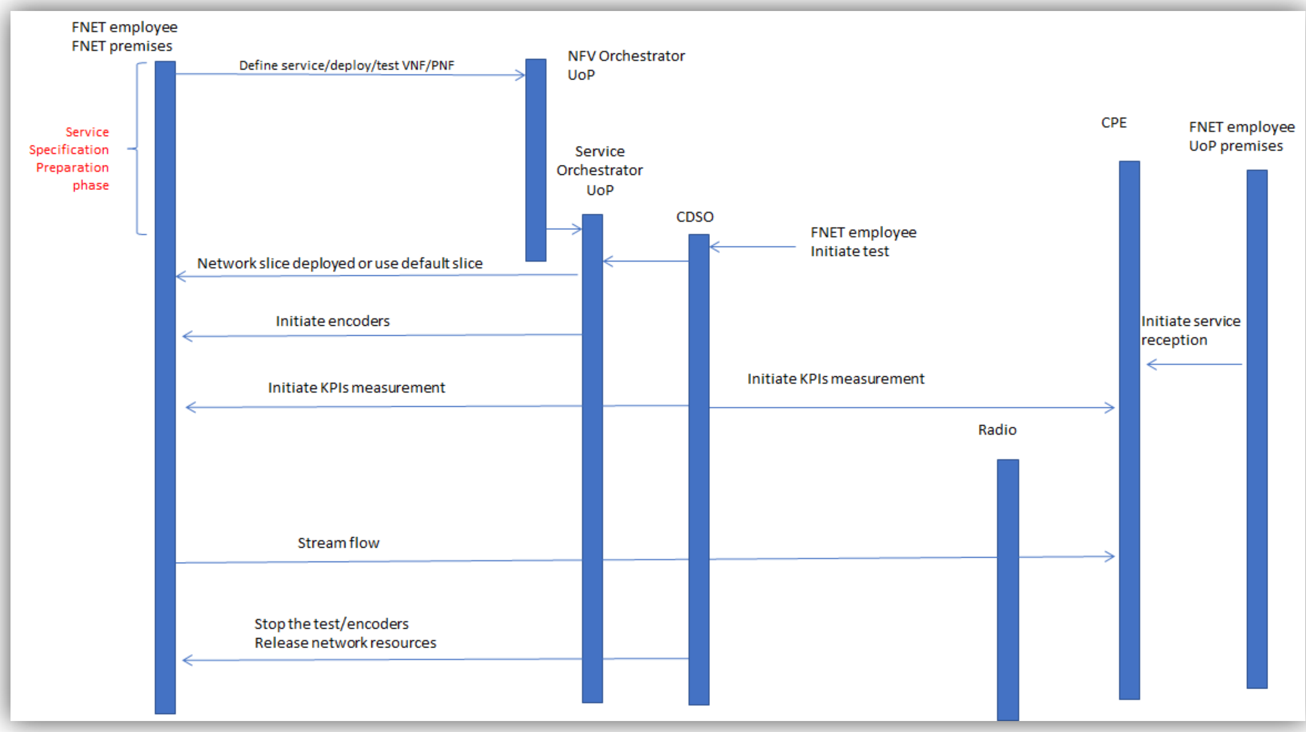

Figure 70: UC4.1 Trial 2 High level information flow diagram

5.4.1.2.5 *Orchestration Flow*

The following flow assumes that the end-to-end infrastructure is established:

Table 50: UC4.1 Orchestration Flow

	Step	Interface with	Comments
		1 User activates experiment UI/API to CDSO	
1.1	UC owner starts the trial	CDSO	The CDSO provides the interface to the UC owner to provide information about the slice parameters and the video stream activation. If needed separate order will be given by the UC owner to configure the slide and activate the streaming.
1.2	Create connection from CDSO to UoP & Authenticate	UoP Orchestrator	Facility site is on https://patras5g.eu/
1.3	Activate encoders 2x Tandberg en8090, TVG420. In addition, at a later a TVG420 decoder in UoP premises will be	No interface to orchestrator. The process is managed by the UoP service orchestrator.	Equipment: Encoders in FNET premises, Decoder in UoP premises Note: A VLC encoder is also installed in UoP premises. This will be continuously operational and there no need to be orchestrated. In needed a VNF will be implemented to control the

	activated		VLC encoder as well. Process: The UoP services orchestrator will request from the OSM VNF orchestrator to activate the respective VNF. Either one VNF per equipment or one VNF addressing all equipment will be implemented. Within the VNF the appropriate SMNP[21] calls will be made towards the respective equipment (e.g. start, stop, etc.)
1.4	Activate Video Stream	No interface to orchestrator. The process is managed by the UoP service orchestrator.	This process is activated by the VNFs
1.5	Visualisation system activation, test start	Visualisation system, UoP Orchestrator	When VNFs are activated according to the previous process the UoP service orchestrator informs CDSO that the infrastructure is set up. Then the CDSO informs the visualization system that it should start measuring the KPIs.
2 Ongoing Status			
2.1	Get streaming equipment status	UoP Orchestrator	Show status. The VNFs will get the equipment status. This information will be given to CDSO through the UoP service orchestrator.
3 User Terminates Experiment UI/API to CDSO			
3.1	UC owner stops the trial	CDSO	The CDSO provides the interface to the UC owner to provide information in order to stop the trial.
3.2	Terminate Video Stream	UoP orchestrator	Then CDSO informs the UoP service orchestrator to terminate the streaming. The UoP services orchestrator sends the command to the OSM VNF orchestrator and the respective VNFs. The VNFs send the stop command to the equipment.
3.3	Terminate KPIs measurement	Visualisation system	When the trial is completed the UC owner will inform CDSO through the interface provided by CDSO. Then CDSO informs the visualization system to stop measuring the KPIs.

5.4.1.2.6 Planned KPIs to be tested

The Encoder Rates used for Trial 2 were the same as in Trial 1. In this experiment, the connection with the Visualization System was not achieved from the UoP VPN, so there are no available KPIs to showcase.

The purpose of this Trial was to test the CDSO for automation of the VNF orchestration, where the initial encoder data rates were automatically set by the CDSO.

5.4.1.2.7 Lessons learned from the deployment

Trial 2 was successfully completed using the CDSO for the rate adjustment and the starting/stopping of the Encoders, automating the VNF orchestration.

[21] https://tools.ietf.org/html/rfc1157

In addition to the Trial 1 lessons learned, we identify the need to collaborate with CDSO and UoP testbed engineers to achieve integration. We propose that in commercial deployments respective tools guiding such integration will need to be provided.

5.4.2 UC4.4: User & Machine Generated Content

5.4.2.1 *UC objective and design*

UC 4.4 is about live professional coverage such as news, events etc. by TV broadcasters and equivalent or better productions. Professional content creation is done more and more in 4K video resolution and in the future in 8K, at high video quality. This requires consistently high bandwidth along with high reliability and low delay. The current professional media production over 4G networks is usually not achievable and requires bonding devices using several 4G modems combined for the uplink transmission.

The goal of the tests in this UC is to understand the UL performance of the 5G network in such cases, for the live video professional production from professional high quality 4K cameras. Over all the testing cycles, the performance of the application and the network will be tested in a standard slice as well as under an enhanced NEM UL “media slice”, using a single 5G connection as well as using bonding of multiple 5G connections.

Partners and components

LiveU will provide a device containing professional H.265 real time video encoder with 5G Embedded transmission modules. It also includes LiveU bonding capabilities, enabling transmission split between two or more modems on the same network or on several networks. This capability will enable the testing of enhanced transmission capabilities by using more than a single network, to gain both bandwidth and stability/reliability. LiveU will also provide the video server receiving the live transmission.

UoP will provide the 5G-VINNI infrastructure and network load simulator, Nokia will provide the CDSO orchestrator that initiates the network service (e.g., “slice”) and to start/stop the test executions, AppART will provide the visualization system that collects, analyses and displays the results and FNET will provide the 4K camera and respective crew which will be deployed at the UoP 5G testbed area.

This use case will be performed during cycle 1 trials.

5.4.2.2 *UC architecture and Information flow*

The test architecture is depicted in the diagram below (Figure 71).

The 4K camera provided by FNET is feeding with live stream. The unit is controlled either by the manual operator or from remote – via the LiveU web-based control SW or in this test case – via the CDSO orchestrator (Nokia).

The CDSO function here is to (a) initiate loading the right service/slice (according to pre-configured parameters defined with CTTC) into the 5G-VINNI platform and (b) “coordinate” and control the test flow by commanding the right LiveU unit to start/stop transmission while informing that to the Visualization system (AppART).

Using the coordination and control information, the Visualization system knows when to start collecting the platform/network information. This enables it to correlate the LiveU application data with the network/platform data.

During the test, the LiveU log files record the application-level performance data such as bandwidth, latency and error rate, per each of the links/modems it uses. After the test ends, the LiveU application log files are manually collected, pre-processed with a special proprietary SW so to extract the relevant information, CSV files are created and manually uploaded into the visualization system portal.

The visualization system analyses and correlates the application performance and the network/platform data. It will show, per modem/IP connection, the bandwidth, latency and error over time from the application level and from the core level. Statistical analysis such as standard deviations will also be done; however detailed information about available statistics is still under investigation and depends on the behavior and meaning of the results.

In cycle 1 we mainly intend to test the basic configuration. We will use a “standard” 5G slice. Depending on time and deployment capacities, we will also test with another slice, the NEM UL slice. Also, we may test 5G+ 4G bonding and/or 5G + WiFi bonding in this cycle, by using the commercial 4G network available (uncontrolled) in this area and/or the UoP WiFi network. For such tests the application level and 5G platform level parameters will still be collected, unlike the 4G or WiFi networks parameters which are not accessible to us.

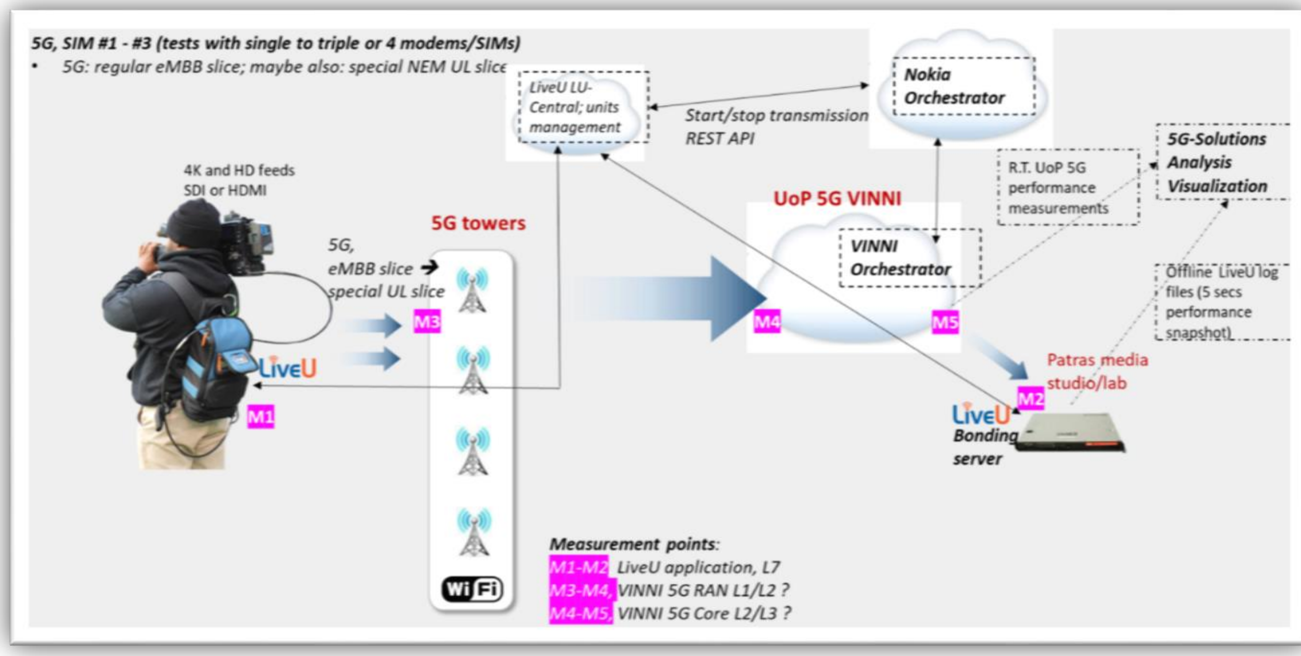

Figure 71: UC4.4 architecture

The control and data flows are illustrated in the figure below:

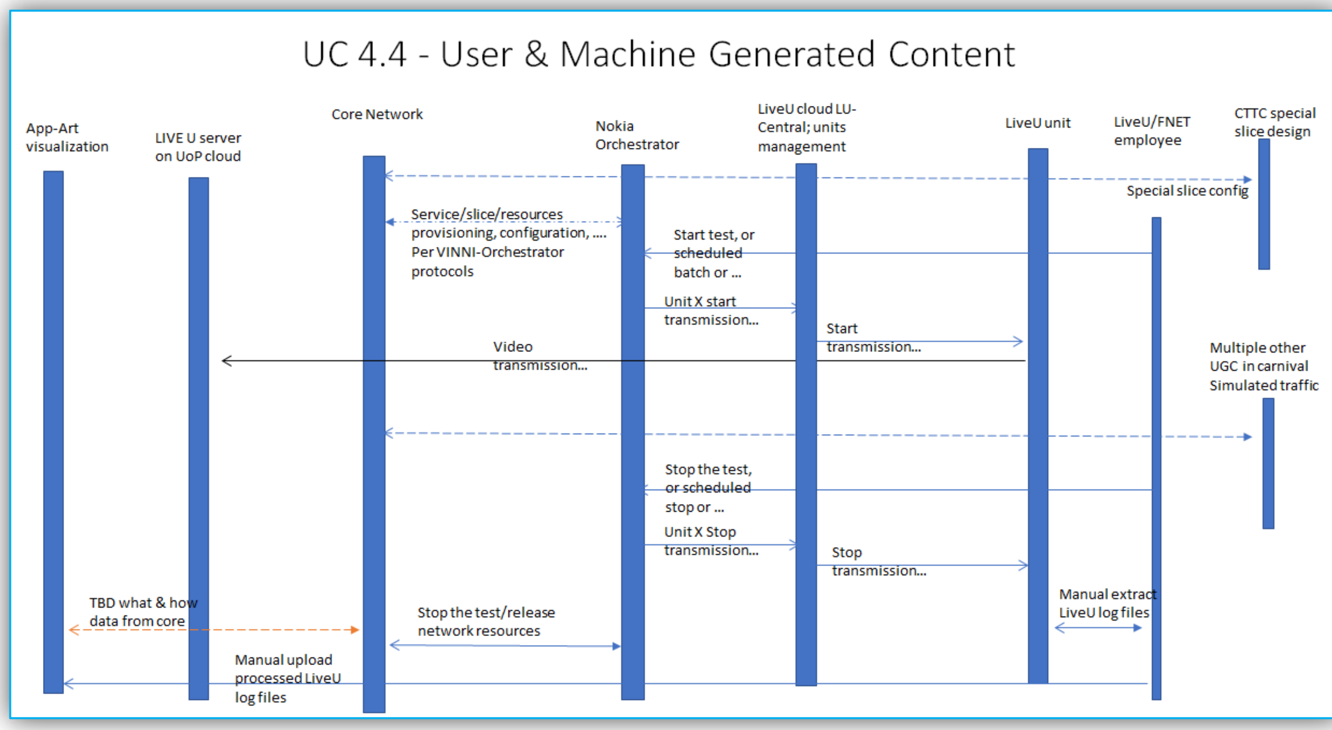

Figure 72: UC4.4 Information flow

5.4.2.3 *Planned KPIs to be tested*

The UC4.4 technical KPIs are listed in the Table below.

Table 51: UC4.4 technical KPIs

Technical KPIs		
KPI	**Target**	**Measurement details**
E2E latency	<5 s (Content delivery network) < 5 ms (Live-TV distribution) <1 ms (6DoF VR) 30 ms (Crowdsourced Video)	Measure E2E latency using packet tracer
Uplink stream latency	<0,5 sec	Including video capture, compression, and transmission to cloud/studio and decoding.
Downstream latency	<0,5 sec	Including encoding/transcoding, transmission not via a CDN, decoding.
Connection density	10K devices per cell	
Mobility	Content Delivery network: 0-5 Km/h for pedestrians. 60-100 Km/h for users in vehicles. Live-TV distribution: 3 Km/h for pedestrians. 50 Km/h for vehicles. 6DoF VR: 10 Km/s	Check whether eMBB.8 is achieved under different mobility scenarios

Two-way throughput (DL+UL)	20 Gbps downlink and 10 Gbps uplink two-way throughputs	Measure peak data rate under uplink and downlink full load
Multi-link reliability	Relevant bandwidth under the various bonding set-ups defined in sub-chapters below; at least 15 Mbps for each uplink continuous transmission	Measure video bandwidth, continuity, breaks, latencies
Dedicated slice setup and tear down timings	<3 minutes	Dynamic, on demand and/or in advance, setup and tear down in specific locations.
Seamless transition of a SIM from eMBB slice to/from dedicated dynamic slice	Continuous, non-interrupted, seamless transfer; <30 sec from set-up. < 5 msec transition time	Ensure that a SIM registered to get service from a dedicated upstream slice can get it seamlessly and without service interruptions

Another goal of these tests is to determine if additional KPIs can be defined and measured. These can include business KPIs, such as:

- the quality increase in the content by having a stable 5G-based 4K transmission, compared to the risk of not having that stable transmission,
- the significance of the impact of reduced battery run-time due to using a 5G modem/module,
- etc.

Some of these additional KPIs also depend on the actual availability of the 5G modules, which is currently delayed by Qualcomm and module vendors due to COVID-19.

5.4.2.4 *Test cases*

Table 52: UC4.4 test scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC4.4-PRE	Pre-trial unit and integration test		A default scenario for pre E2E testing	To carry out all the necessary unit and integration testing before E2E can start
UC4.4-SC1	Scenario-B: Live feed with 1 UL modem transmission, eMBB	N-SC	Scenario-B: Live HEVC transmitted 4k feed using a single 5G modem (several bandwidths to be tested in the range of 10 to 50Mbps), standard eMBB slice	Evaluate network management strategies. Evaluate UL video contribution of professional video over standard slice.
UC4.4-SC2	Scenario-C: Live feed with 2 UL bonded modems, eMBB	N-SC	Scenario-C: Live HEVC transmitted 4k feed using two bonded 5G modems (several bandwidths to be tested in the range of 10 to 50Mbps), standard eMBB slice	Evaluate network management strategies. Evaluate UL video contribution of professional video over standard slice using 2 5G modems bonded.
UC4.4-SC3	Scenario-D: Live feed with 1 UL modem	N-SC	Like B, but over NEM UL Slice	Evaluate network management strategies. Evaluate UL video

	transmission, eMBB			contribution of professional video over UL SLA slice.
NC4.4-SC1	Scenario-E: Live feed with 2 UL bonded modems, eMBB	N-SC	Like C, but over NEM UL Slice	Evaluate network management strategies. Evaluate UL video contribution of professional video over UL SLA slice using 2 5G modems bonded.
NC4.4-SC2	Scenario NEM media slice (UL)	N-SC	could be a network scenario that could be described	Evaluate network management strategies. Evaluate UL video contribution of professional video over standard slice.
NC4.4-SC3	Scenario Other media slice 1	N-SC	could be a network scenario that could be described	Evaluate network management strategies. Evaluate UL video contribution of professional video over standard slice.

Table 53: UC4.4 test areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC4.4-TA1	LiveU Side - 5G device preparation	Unit, Component Test	Development of the 5G video encoder and transmitter; Note: the current LiveU LU600 5G device is capable of processing up to ~50mbps, so this is set as the limit for this cycle. In the future, the LU800 will be launched and should be able to process up to ~80 Mbps, and that will be the limit for cycle 2 or 3. Evaluate 5G modules for the device integration, test the modules and the device over 4G (no 5G in Israel)	Prepare the LiveU 5G device
UC4.4-TA2	LiveU/Appart Side -Visualization system	Integration Test	Integration with the visualization system via LiveU unit log files	To test the visualization system processing of the log files according to log files specs and workflow
UC4.4-TA3	Liveu/UoP Side-UoP testbed	Integration & E2E Test	Install LiveU video server LU2000 in UoP testbed and test E2E video contribution from Israel to UoP.	To have a functional receiving server in UoP private cloud, capable of receiving 4K video transmissions from remote. This is the server that will later

				receive the 5G transmissions from the testbed
UC4.4-TA4	Liveu side - 5G device testing in 5G	Unit, Component Test	Test LiveU new 5G device in a 5G network. TBD, either directly in UoP or in other networks previously.	To verify the ability of the LiveU device to transmit in 5G networks, single link and bonded video.
UC4.4-TA5	Liveu/CDSO (Nokia)	Integration Test	Integrate CDSO with LiveU LU-Central	To test the ability of the CDSO to coordinate the start/stop transmissions from LiveU field devices, according to LiveU API spec
UC4.4-TA6	E2E Use Case	E2E Test	E2E integration, onboarding (PNFs), orchestration via CDSO, connection to the visualization system, slice establishment (NEM 5G media slice, other slices will be tested too), end2end connectivity, end2end KPIs measurement	To test different stream characteristics to measure the impact on the KPIs.

Table 54: UC4.4 TC01-TC05 TCs Matrix

	TC01	**TC02**	**TC03**	**TC04**	**TC04**
Test Areas	UC4.4-TA1	UC4.4-TA1	UC4.4-TA1	UC4.4-TA1	UC4.4-TA1
Target Vertical KPIs - Primary & Secondary					
Peak Data Rate				3rd	3rd
Latency				1st	1st
Area traffic capacity					
Throughput per 4K video stream				2nd	2nd
Mobility					
Connection Density					
Media request response time					
Scenario ID					
UC4.4-PRE	x	x	x	x	x
UC4.4-SC1					
UC4.4-SC2				x	x
UC4.4-SC3				x	x
NC4.4-SC1				x	x
NC4.4-SC1				x	x
NC4.4-SC2					

Table 55: UC4.4 TC06-TC08 TCs Matrix

	TC06	TC07	TC08
Test Areas	UC4.4-TA6	UC4.4-TA6	UC4.4-TA6
Target Vertical KPIs - Primary & Secondary			
Peak Data Rate	3rd	3rd	3rd
Latency	1st	1st	1st
Area traffic capacity			
Throughput per 4K video stream	2nd	2nd	2nd
Mobility			
Connection Density			
Media request response time			
Scenario ID			
UC4.4-PRE			
UC4.4-SC1		x	
UC4.4-SC2	x		x
UC4.4-SC3	x		x
NC4.4-SC1	x		
NC4.4-SC1	x		
NC4.4-SC2		x	x

5.4.3 UC4.6: Cooperative Media Production

5.4.3.1 *UC Objective and design*

UC4.6 is about enablement of remote or collaborative production of live professional events by TV broadcasters and equivalent or better productions. Remote Production is attracting a lot of attention. It is expected to be an evolution in content production. Being still an evolving area and due to a large variance in the events and their means of coverage, different types and variations of remote or collaborative productions exists. For example, multiple cameras transmitting live from an event removes the necessity of sending a full production team and equipment set to the event. Instead, only cameras and the camera-team can be sent while the production itself is done over these feeds in the studio or in the cloud. In any case, 5G is expected to play an important role in enabling such scenarios. This requires consistently high bandwidth along with high reliability and low delay for several cameras at high quality and in-sync in terms of delay.

The goal of the tests in this UC is to understand the UL performance of the 5G network in such cases for the live video professional collaborative or remote production from multiple 4K cameras and at synchronized delays. Over all the testing cycles, the performance of the application and the network will be tested in a standard slice as well as under an enhanced NEM UL “media slice”, using a single 5G connection as well as using bonding of multiple 5G connections.

Partners and components

LiveU will provide several devices containing professional H.265 real time video encoder with 5G embedded transmission modules. The devices also include LiveU bonding capabilities, enabling transmission split between two or more modems on the same network or on several networks. This capability will enable testing of enhanced transmission capabilities by using more than a single network, to gain both bandwidth and stability/reliability. The transmission algorithms enable synched transmission of multiple cameras from multiple devices at identical latencies, assuming that the network performance will provide latency which is lower enough to allow such synchronization. LiveU will also provide the video server receiving the live transmission.

UoP will provide the 5G-VINNI infrastructure and the network load simulator while Nokia will provide the CDSO orchestrator that initiates the network service (e.g., "slice") and start/stop the test executions. AppArt will provide the visualization system that collects, analyses and displays the results and FNET will provide 4K cameras and the respective crew.

This use case will be performed during cycle 1 trials.

5.4.3.2 *UC architecture and Information flow*

The test architecture and flow are defined in the diagrams below.

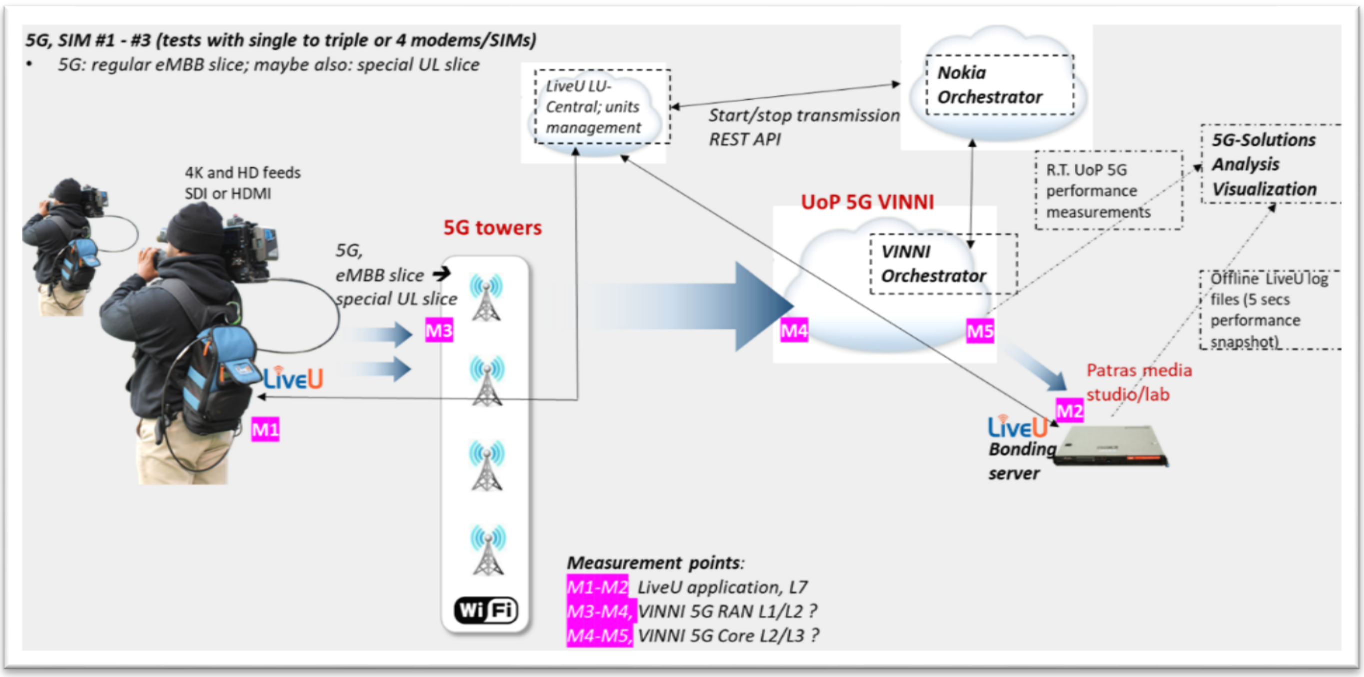

Figure 73: UC4.6 Architecture

Basically, in cycle 1 it is similar to UC4.4 except that we will use two LiveU units transmitting simultaneously. Both will be set to the minimal possible latency that also provides stable fixed-latency transmission using the LiveU synchronized bonding and fixed latency transmission capabilities. The data and control flows are illustrated below:

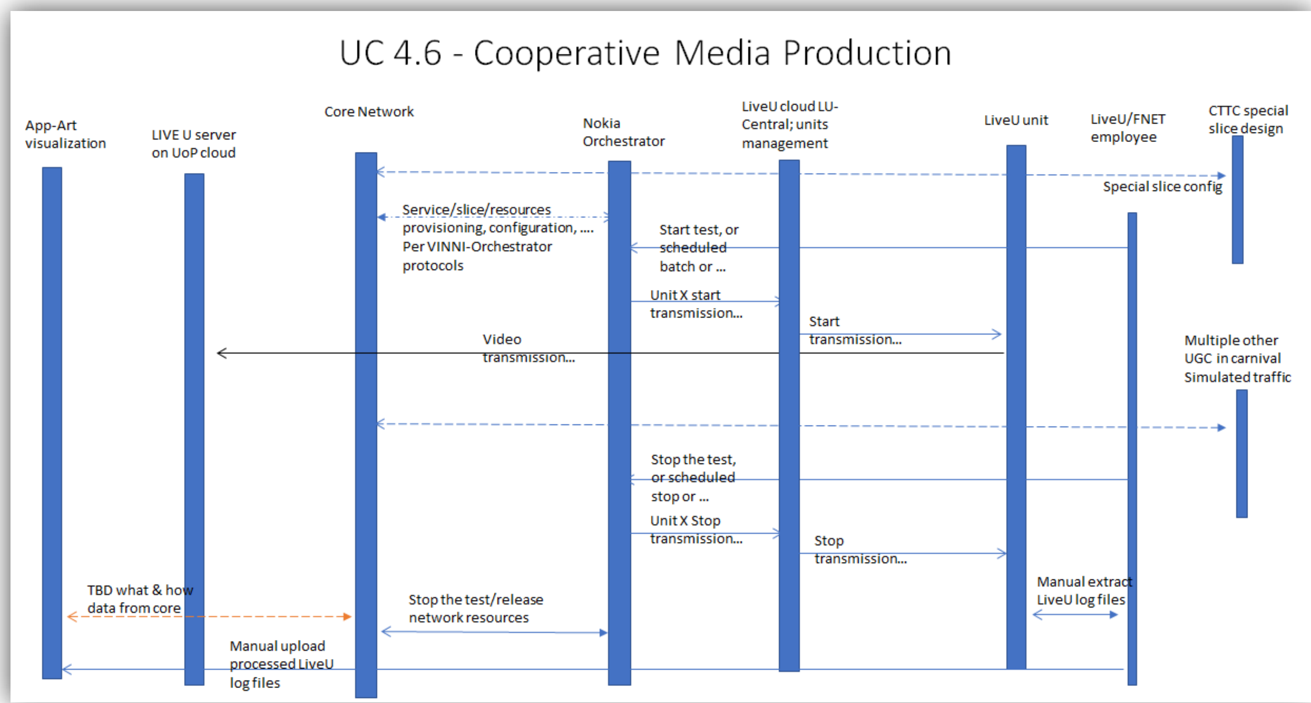

Figure 74: UC4.6 Information flow

As the Patras summer Festival was cancelled due to the COVID-19 pandemic, the tests have to be carried out either in-lab or wherever the 5GVINNI platform is installed, and without load or real world "action" festival. However, this has its own advantage, as the timing of the tests, the durations, the logistics complexities and limitations are much relaxed which enables us to collect insights and understandings toward the next cycles where more complex tests will be conducted.

5.4.3.3 *Planned KPIs to be tested*

The test KPIs are:

Table 56: UC4.6 Technical KPIs

Technical KPIs		
KPI	**Target**	**Measurement details**
Latency	<5 s (Content delivery network) 30 ms (Crowdsourced Video)	Measure latency using packet tracer.
Synchronization	< 0.5 sec	Measured between multiple synchronized bonded transmissions, at the remote production SW.
Throughput per 4K video stream	~15 Mbps	Measure throughput per device for 4K video stream.

Another goal of these tests is to define and address additional KPIs. These could include business KPIs, such as:

- the potential overall cost reduction in production due to this remote production over 5G,
- the potential range of new cases where cellular-based remote production may be applicable due to the 5G performance,

- performance over Non-Public-Network (NPN) as a potential indicator to relevant UL performance over Public Network (if such deduction can be drawn at all),
- cost and ROI related KPIs to deploying NPN for such a use case,
- the simplicity/complexity in defining special dedicated media UL slice, quality increase in the content by having a stable 5G-based 4K transmission compared to the risk of not having that stable transmission,
- the significance of the impact of reduced run-time due to using a 5G modem/module, etc.

Some of these KPIs will be defined as a result of the Cycle 1 test, whereas for some a definitive answer might not be yet identified. Some of these additional KPIs also depend on the actual availability of the 5G modules, which are currently being very much delayed by Qualcomm and module vendors.

5.4.3.4 *Test cases*

Table 57: UC4.6 Test Scenarios

SC ID	Scenario Name	Scenario Type	Description	Test Objective(s)
UC4.6-PRE	Pre-trial unit and integration test		A default scenario for pre E2E testing; Note: the current LiveU LU600 5G device is capable of processing up to ~50mbps, so this is set as the limit for this cycle. In the future, the LU800 will be launched and should be able to process up to ~80 Mbps, and that will be the limit for cycle 2 or 3. Two video streams are to be outputted synchronously.	To carry out all the necessary unit and integration testing before E2E can start
UC4.6-SC1	Scenario-B: Live feed with 2 camera-transmitter pairs, each with 1 5G modem, eMBB	N-SC	Scenario-B: Live feed with 2 cameras, each connected to a 5G bonding device but with just 1 modem transmitting, identical latency (few tests at: 0.8sec 1sec, 1.5 sec) set in both bonding devices (bandwidth for each transmitter range from 3Mbps for HD to 25Mbps for 4K), eMBB slice; two video streams to be outputted synched.	Evaluate network management strategies. Evaluate UL video contribution performance on standard slice, including two transmitters video feed synch/fixed latency.
UC4.6-SC2	Scenario-C: Live feed with 2 camera-transmitter pairs, each with 2x 5G modems bonded, eMBB	N-SC	Scenario-B: Live feed with 2 cameras, each connected to a 5G bonding device having 2 modems each, identical latency (few tests at: 0.8sec 1 sec, 1.5 sec) set in both bonding devices, (bandwidth for each transmitter range from 7Mbps for HD to 50Mbps for 4K), eMBB slice	Evaluate network management strategies. Evaluate UL video contribution performance on standard slice, two bonded 5G transmitters, including two transmitters video feed synch/fixed latency.
UC4.6-SC3	Scenario-D: Live feed with 2 camera-transmitter	N-SC	Same as B, but use both transmitters on the NEM UL slice	Evaluate network management strategies. Evaluate UL video

	pairs, each with 1 5G modem, NEM UL slice			contribution performance on special UL SLA slice, including video feed synch.
NC4.6-SC1	Scenario-E: Live feed with 2 camera-transmitter pairs, each with 2x 5G modems bonded, NEM UL slice	N-SC	Same as C, but use both transmitters on the NEM UL slice	Evaluate network management strategies. Evaluate UL video contribution performance on special SLA slice, two bonded 5G transmitters, including two transmitters video feed synch/fixed latency.
NC4.6-SC1	Scenario NEM media slice (UL), same as	N-SC	could be a network scenario that could be described	Evaluate network management strategies. Evaluate UL video contribution performance on standard slice, including two transmitters video feed synch/fixed latency.
NC4.6-SC2	Scenario Other media slice 1	N-SC	could be a network scenario that could be described	Evaluate network management strategies. Evaluate UL video contribution performance on standard slice, including two transmitters video feed synch/fixed latency.

Table 58: UC4.6 Test Areas

TA ID	Test Area	Test Level	Description	Test Objective(s)
UC4.6-TA1	LiveU Side - 5G device preparation	Unit, Component Test	Development of the 5G video encoder and transmitter device, evaluate 5G modules for the device integration, test the modules and the device over 4G (no 5G in Israel)	Prepare the LiveU 5G device
UC4.6-TA2	Forthnet side	Integration test	Test that multiple video feeds being received at the LiveU video server placed in UoP is integrated into the Forthnet OTT platform	Ensure the video workflow between the two main segments: the contribution (LiveU) and the OTT (Forthnet), using the UoP IP cloud interconnections
UC4.6-TA3	LiveU/Appart Side - Visualization system	Integration Test	Integration with the visualization system via LiveU unit log files	To test the visualization system processing of the log files according to log files specs and workflow

UC4.6-TA4	Liveu/UoP Side-UoP testbed	Integration & E2E Test	Install LiveU video server LU2000 in UoP testbed and test E2E video contribution from Israel to UoP.	To have a functional receiving server in UoP private cloud, capable of receiving 4K video transmissions from remote. This is the server that will later receive the 5G transmissions from the testbed
UC4.6-TA5	Liveu side - 5G device testing in 5G	Unit, Component Test	Test LiveU new 5G device in a 5G network. TBD, either directly in UoP or in other networks previously.	To verify the ability of the LiveU device to transmit in 5G networks, single link and bonded video.
UC4.6-TA6	Liveu/CDSO (Nokia)	Integration Test	Integrate CDSO with LiveU LU-Central	To test the ability of the CDSO to coordinate the start/stop transmissions from LiveU field devices, according to LiveU API spec
UC4.6-TA7	E2E Use Case	E2E Test	E2E integration, onboarding (PNFs), orchestration via CDSO, connection to the visualization system, slice establishment (NEM 5G media slice, other slices will be tested too), end2end connectivity, end2end KPIs measurement	To test different stream characteristics to measure the impact on the KPIs.

Table 59: UC4.6 TC01-TC05 TCs Matrix

	TC01	TC02	TC03	TC04	TC04
Test Areas	UC4.6-TA1	UC4.6-TA2	UC4.6-TA3	UC4.6-TA4	UC4.6-TA5
Target Vertical KPIs - Primary & Secondary					
Peak Data Rate				3rd	3rd
Latency				1st	1st
Area traffic capacity					
Throughput per 4K video stream				2nd	2nd
Mobility					
Connection Density					
Media request response time					
Scenario ID					
UC4.6-PRE	x	x	x	x	x
UC4.6-SC1					
UC4.6-SC2				x	x
UC4.6-SC3				x	x
NC4.6-SC1				x	x

NC4.6-SC1				x	x
NC4.6-SC2					

Table 60: UC4.6 TC06-TC08 TCs Matrix

	TC06	TC07	TC08
Test Areas	UC4.6-TA6	UC4.6-TA6	UC4.6-TA6
Target Vertical KPIs - Primary & Secondary			
Peak Data Rate	3rd	3rd	3rd
Latency	1st	1st	1st
Area traffic capacity			
Throughput per 4K video stream	2nd	2nd	2nd
Mobility			
Connection Density			
Media request response time			
Scenario ID			
UC4.6-PRE			
UC4.6-SC1		x	
UC4.6-SC2	x		x
UC4.6-SC3	x		x
NC4.6-SC1	x		
NC4.6-SC1	x		
NC4.6-SC2		x	x

5.5 MLL: UC4.1 and UC4.4

5.5.1 UC test objective and design

One of the challenges of 5G is to validate its technological and business performance across all sets of heterogeneous requirements stemming from concurrent usage of network resources by different vertical domains. In this respect, relevant field trials will be conducted concurrently with multiple vertical use cases. The purpose is to validate and capture evidence through the relevant performance KPIs to what extent virtualization is capable of successfully managing testbed resources, and how these capabilities are in line with such concurrent performance requirements and also, that there is no interference between vertical use cases in the presence of concurrent usage of resources (i.e., strict isolation is maintained).

To support network management, dynamic service lifecycle automation and automatic real-time and concurrent orchestration across the UoP facility, the CDSO is leveraged, to bind all 5G-related services to be piloted and to control their flows.

Therefore, this joins and executes in a combined and concurrent manner those use cases from LL4 whose target KPI requirements (i.e., high throughput, low latency, etc.) have to be met.

In MLL, various UCSs are built to validate the capability of NOP and CSP to provide assured network services to multiple vertical customers concurrently. These UCSs are designed in a progressive way while complexity and difficulties increase. In Cycle 1, relatively simpler UCSs (e.g., with simpler combinations) are planned, mostly by reusing LL4 UC4.1: Ultra High-Fidelity Media and UC4.4: User & Machine Generated Contentand, e.g., concurrent execution of multiple instances of a single UC. More advanced UCSs will be created in Cycle 2 and 3 (even beyond) to verify more complex combinations.

The MLL performed cycle 1 trials alongside the UC4.1 and UC4.4.

5.5.2 Test planning

The preparations are managed by FNET. In the week of June 28th to July 7th, 2021 MLL is planned to be performed combining UC4.1 and UC4.4. The tests will be done both remotely, mainly for indoor tests, and also on-site, mainly for outdoor tests. In the MLL activity all UC owners (FNET, LiveU) and partners (UoP, Nokia and App-art) will participate. UoP will be the facilitator and host of the tests and took care of many needs this project requires.

The following tests were planned during the MLL:

1. UC4.4 alone indoor
2. UC4.1 alone indoor
3. UC4.4+UC4.1 together indoor
4. UC4.4 alone outdoor
5. UC4.4+UC4.1 together outdoor

It is agreed to divide the tests to indoor and outdoor where the indoor tests will be performed remotely on June 28-29th and the outdoor tests will be performed onsite on July 1st.

5.5.3 UC Architecture

From UC4.1 the same architecture as seen in Section 5.4.1will be used (Figure 67). Again, two encoders are deployed in FNET premises in Athens and the two Tandberg encoders stream the signal while the TVG420 encoder is used to multiplex the signals and create a demand for higher throughput.

From UC4.4 the same architecture as seen in Section 5.4.2 (Figure 71), but only with LU800, will be used.

Both of the above architectures will be combined for the MLL Trials in order to jointly run the necessary test scenarios. Furthermore, as previously the the APPART Visualization System (VS) will be used to aggregate and visualize the KPIs.

The architecture of MLL Trials (UC4.1 and UC4.4) is illustrated in Figure 75 below.

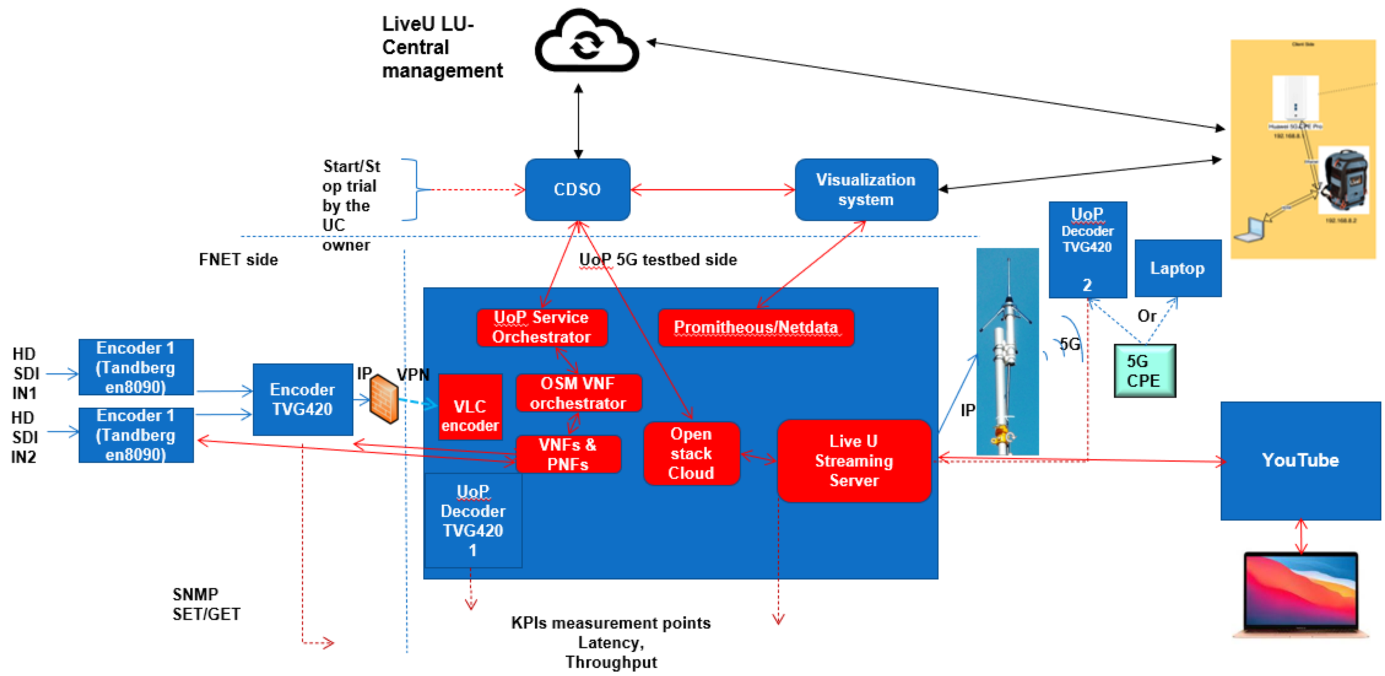

Figure 75: MLL Cycle 1 trials architecture

5.5.4 Information sequence diagram

In order to define test scenarios and entities involved, a high-level flow diagram was defined as presented in Figure 76.

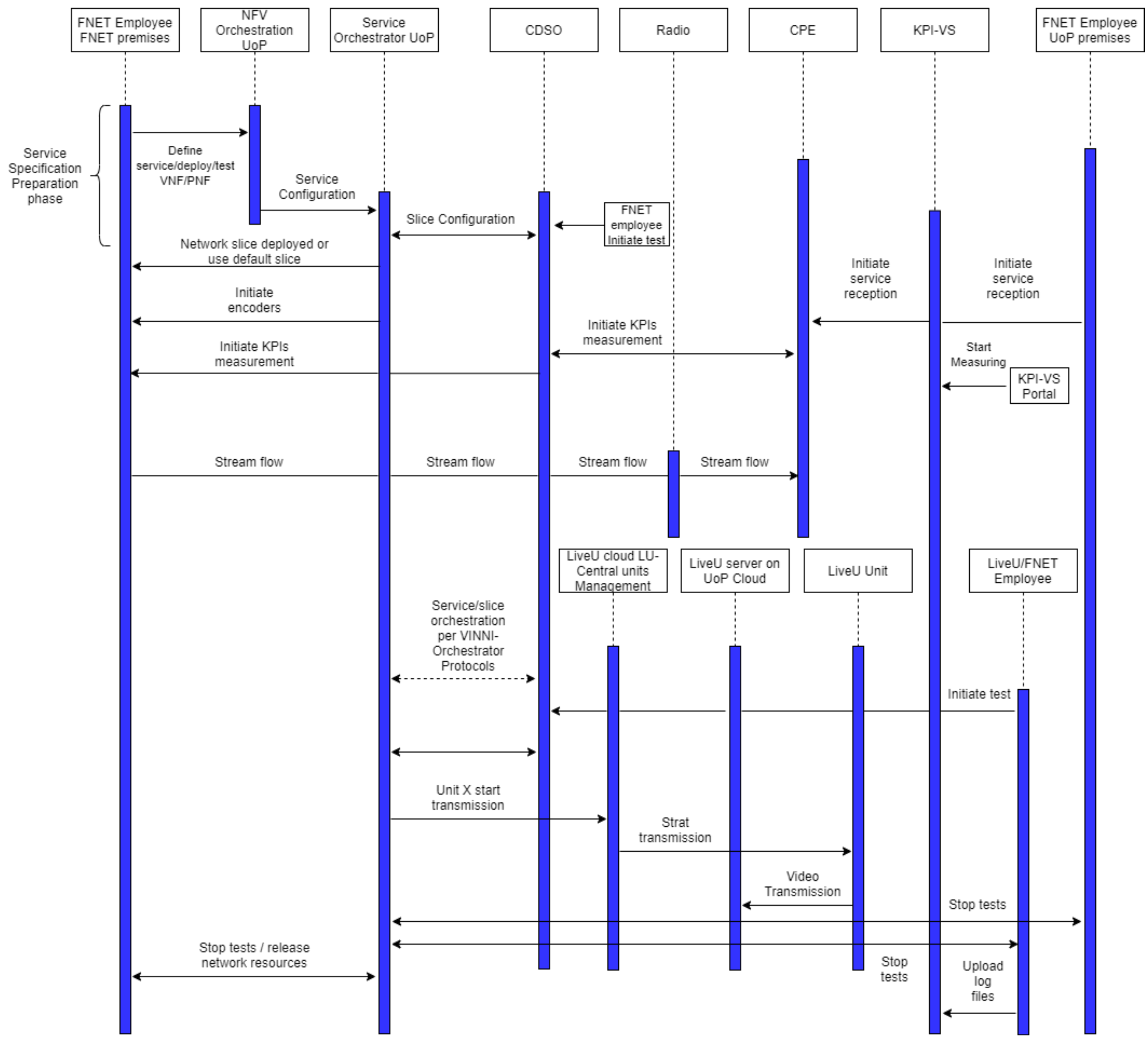

Figure 76: MLL Trial High level information flow diagram

5.5.5 Orchestration flow

Table 61: UC4.1 Orchestration Flow

	Step	Interface with	Comments
1 User activates experiment UI/API to CDSO			
1.1	UC4.1 owner starts the trial	CDSO	The CDSO provides the interface to the UC owner to provide information about the slice parameters and the video stream activation. If needed separate order will be given by the UC owner to configure the slide and activate the streaming.
1.2	Create connection from CDSO to UoP & Authenticate	UoP Orchestrator	Facility site is on https://patras5g.eu/

1.3	Activate encoders	No interface to orchestrator. The process is managed by the UoP service orchestrator.	Equipment: Encoders in FNET premises, Decoder in UoP premises
1.4	UC4.4 Create connection from CDSO to LiveU Central & Authenticate	LiveU Central (LUC)	LiveU Central is in the cloud.
1.5	CDSO queries LU-Central for the LiveU units online	LiveU Central	This is not mandatory but desired for this C1. We have two units in UoP. We can limit the CDSO involvement to one of themt, but prefer to do with both, as agreed a while ago.
1.6	Activate Video Stream for both UCs	No interface to orchestrator. The process is managed by the UoP service orchestrator.	This process is activated by the VNFs
1.7	Visualisation system activation, test start	Visualisation system, UoP Orchestrator	When VNFs are activated according to the previous process the UoP service orchestrator informs CDSO that the infrastructure is setup. Then the CDSO informs the visualization system that it should start measuring the KPIs.
2 Ongoing Status			
2.1	Get streaming equipment status	UoP Orchestrator	Show status. The VNFs will get the equipment status. This information will be given to CDSO through the UoP service orchestrator.
2.2	Get equipment Status from Orchestrator	CDSO	Send status to KPI-VS and use it for internal mechanism
2.3	Get stream status	LiveU Central	Gather and show status.
3 User Terminates Experiment UI/API to CDSO			
3.1	UC owner stops the trial	CDSO	The CDSO provides the interface to the UC owner to provide information in order to stop the trial.
3.2	Terminate Video Stream	UoP orchestrator	Then CDSO informs the UoP service orchestrator to terminate the streaming. The UoP services orchestrator sends the command to the OSM VNF orchestrator and the respective VNFs. The VNFs send the stop command to the equipment.
3.3	Terminate KPIs measurement	Visualisation system	When the trial is completed the UC owner will inform CDSO through the interface that CDSO will provide. Then CDSO informs the visualization system to stop measuring the KPIs.

5.5.6 Planned KPIs to be tested

For the MLL trials the same KPIs as shown at the section UC4.1: Ultra High-Fidelity Media and UC4.4: User & Machine Generated Content are planned to be tested with focus on the effects that will be observed when two UCs are tested at the same time. The goal is to have a comparison between the stand-alone UCs and the concurrent ones.

5.5.7 Test cases and scenarios definition

The indoor tests will be very similar to cycle 1 tests with similar KPIs and results.

During a telco, the synchronization between the UCS will be done manually. CSDO will run the network service and the VS will collect network data.

The outdoor tests are more challenging logistically. UoP will arrange a table at the parking lot of the department with all the needed equipment. FNET will bring a long (~80 meter) SDI to tests also long-distance streaming with the LiveU unit, so it will be possible to test roughly 100 meters from the base station and 200 meters.

Same as in the indoor tests, both UC will perform standalone tests and combined tests using different configurations and steps. Overall, 31 tests are planned.

All the above will then reflect the case where multiple vertical enterprise customers are sharing either a single slice or multiple slices.

In more detail the test cases for the trials can be shown in Table 62.

Table 62: MLL UC4.1 along UC4.4 Test Cases

MLL Test Case	UC4.1 Test Case	UC4.4 Test Case	Location	Key values
TC1	2 decoders – Bit Rate 7.5 Mbps	Black Magic Device - Latency 0.8s	Indoor	Latency, Throughput, Lost Frames
TC2	2 decoders – Bit Rate 15.6 Mbps	Black Magic Device - Latency 0.8s	Indoor	Latency, Throughput, Lost Frames
TC3	2 decoders – Bit Rate 26 Mbps	Black Magic Device - Latency 0.8s	Indoor	Latency, Throughput, Lost Frames
TC4	2 decoders – Bit Rate 7.5 Mbps	Black Magic Device - Latency 1s	Indoor	Latency, Throughput, Lost Frames
TC5	2 decoders – Bit Rate 15.6 Mbps	Black Magic Device - Latency 1s	Indoor	Latency, Throughput, Lost Frames
TC6	2 decoders – Bit Rate 26 Mbps	Black Magic Device - Latency 1s	Indoor	Latency, Throughput, Lost Frames
TC7	1 decoder – Bit Rate	Camera - Latency	Outdoor	Latency,

	7.5 Mbps	0.6s		Throughput, Lost Frames
TC8	1 decoder – Bit Rate 15.6 Mbps	Camera - Latency 0.6s	Outdoor	Latency, Throughput, Lost Frames
TC9	1 decoder – Bit Rate 26 Mbps	Camera - Latency 0.6s	Outdoor	Latency, Throughput, Lost Frames
TC10	1 decoder – Bit Rate 7.5 Mbps	Camera - Latency 0.8s	Outdoor	Latency, Throughput, Lost Frames
TC11	1 decoder – Bit Rate 15.6 Mbps	Camera - Latency 0.8s	Outdoor	Latency, Throughput, Lost Frames
TC12	1 decoder – Bit Rate 26 Mbps	Camera - Latency 0.8s	Outdoor	Latency, Throughput, Lost Frames
TC13	1 decoder – Bit Rate 7.5 Mbps	Camera - Latency 1s	Outdoor	Latency, Throughput, Lost Frames
TC14	1 decoder – Bit Rate 15.6 Mbps	Camera - Latency 1s	Outdoor	Latency, Throughput, Lost Frames
TC15	1 decoder – Bit Rate 26 Mbps	Camera - Latency 1s	Outdoor	Latency, Throughput, Lost Frames

The test cases were divided in two main categories depending on their location (indoor, outdoor). During the first day of MLL trials the indoor tests took place focusing on three scenarios from UC4.1 (Bit Rates of 7.5 Mbps, 15.6 Mbps, 26 Mbps) and on two scenarios from UC4.4 side (Latency: 0.8s, 1s). On the second day of trials, the outdoor tests were implemented, which were concentrated on three scenarios from UC4.1 (Bit Rates of 7.5 Mbps, 15.6 Mbps, 26 Mbps) and on three scenarios from UC4.4 side (Latency: 0.6s, 0.8s, 1s)

5.5.8 Lessons learned from deployment

MLL trials deployment and VNF implementation can be achieved and at this stage the testbed is able to handle both Use Cases and gather the data needed from the Visualization System. In order to implement both tests at the same time, the preparations needed to be done in a more detailed and synchronized manner, because of the complexity of the test and the number of partners involved. From the two test scenarios, indoor and outdoor, it is apparent that the onsite meeting will provide the basis to run the tests together.

Additionally, the integration of the CDSO to the testbed will play a key role, especially in UC4.1. Regarding the LiveU UC4.4, the flow on new units will be done manually and it is apparent that the automation through the CDSO is needed for future tests, along with the use of the VS System to gather all the necessary information.

6. Conclusions and Next Actions

In this deliverable the project consortium analyzed the planning for the Cycle 1 trials for all those UCs that participate. Effort was put in order for all LLs to be adequately represented in this set of trials in order to acquire experiences which will be used in order to mature the deployment of all UCs in the forthcoming Cycles.

Therefore, LL1 has 4 UCs deployed in Cycle1, LL2 3 UCs, LL3 4 UCs (two of which are considered as best effort) and LL4 3 UCs. These UCs are defined at different maturity levels, but the lessons we get from these deployments are applicable to all 5G-SOLUTIONS 20 UCs and will be carried on into the next Cycle.

During Phase II the UCs planning for Cycle 1 trials dealt with a number of uncertainties. Nevertheless, planning progressed to a significant level enabling consistent deployment of all selected UCs to the respective test beds.

Such uncertainties were:

- The testbeds are still under development. The UCs had to work closely with the testbed owners in order to understand the current infrastructure status and plan technical developments in the UCs that are able to use such evolving testbed facilities.
- Due to COVID-19 lockdown access to the majority of facilities was prohibited or impeded. This this end, the deployments of the proposed UCs architecture were based on the existing information and the respective theoretical analysis. Nevertheless, the consortium believes that even if the UCs deployment planning was based mainly on a theoretical approach, we will be able to address the upcoming issues when physical deployment to the testbeds is allowed.

The identification of the use case architectures, test scenarios and requirements towards the testbeds described in this deliverable provides a solid ground for the technical and business evaluations of the 5G-SOLUTIONS verticals that will be completed in Cycle 3 trials.

This deliverable will be updated on M30 (D2.9-D2.4B), so that updated planning, deployment and measurements specifications will be analyzed based on the learning of each preceding trial Cycle.

Annex I: UC3.2 Data Model and the associated REST API results

The data model is defined as shown below:

- id : Unique identifier.
- type : Entity type. It must be equal to *OffStreetParking* or *OnStreetParking*.
- source : A sequence of characters giving the source of the entity data.
  - Attribute type: Property. **Text** or **URL**
  - Optional
- dataProvider : Specifies the URL to information about the provider of this information
  - Attribute type: Property. **URL**
  - Optional
- dateCreated : Entity's creation timestamp
  - Attribute type: Property. **DateTime**
  - Read-Only. Automatically generated.
    - Attribute type: Property. **Text** or **URL**
    - Optional

dateModified : Last update timestamp of this entity

- Attribute type: Property. **DateTime**
- Read-Only. Automatically generated.

status : Status of the parking site.

- Attribute type: Property. List of **Text**
- Metadata:
  - timestamp : Timestamp of the last attribute update
  - Type: **DateTime**
- Allowed values: The following defined by the following enumerations defined by DATEX II version 2.3 :
  - *ParkingSiteStatusEnum*
  - *OpeningStatusEnum*
  - (open, closed, closedAbnormal,openingTimesInForce, full, fullAtEntrance, spacesAvailable, almostFull)
  - Or any other application-specific
- Optional

location : Geolocation of the parking site represented by a GeoJSON (Multi)Polygon or Point.

- Attribute type: GeoProperty. geo:json.
- Normative References: **https://tools.ietf.org/html/rfc7946**
- Mandatory if address is not defined.

address : Registered parking site civic address.

- Attribute type: Property. **Address**
- Normative References: **https://schema.org/address**
- Mandatory if location is not defined.

name : Name given to the parking site.

- Attribute type: Property. **Text**
- Normative References: https://uri.etsi.org/ngsi-ld/name equivalent to **name**
- Mandatory

description : Description about the parking site.

- Attribute type: Property. **Text**
- Normative References: https://uri.etsi.org/ngsi-ld/description equivalent to **description**
- Optional

image : A URL containing a photo of this parking site.

- Normative References: **https://schema.org/image**
- Optional

category : Parking site's category(ies). The purpose of this field is to allow to tag, generally speaking, off street parking entities. Particularities and detailed descriptions should be found under the corresponding specific attributes.

- Attribute type: Property. List of **Text**
- Allowed values:
  - (public, private, publicPrivate, urbanDeterrentParking, parkingGarage, parkingLot, shortTerm, mediumTerm, longTerm, free, feeCharged, staffed, guarded, barrierAccess, gateAccess, freeAccess,forElectricalCharging, onlyResidents, onlyWithPermit, forEmployees, forVisitors, forCustomers, forStudents, forMembers, forDisabled, forResidents, underground, ground)
  - The semantics of the forxxx values is that the parking offers specific spots subject to that particular condition.
  - The semantics of the onlyxxxvalues is that the parking only allows to park on that particular condition.
  - Other application-specific
- Mandatory

allowedVehicleType : Vehicle type(s) allowed. The first element of this array *MUST* be the principal vehicle type allowed. Free spot numbers of other allowed vehicle types might be reported under the attribute extraSpotNumberand through specific entities of type *ParkingGroup*.

- Attribute type: Property. List of **Text**
- Allowed Values: The following values defined by *VehicleTypeEnum*, **DATEX 2 version 2.3**:

        - (agriculturalVehicle, bicycle, bus, car, caravan, carWithCaravan, carWithTrailer,constructionOrMaintenanceVehicle, lorry, moped, motorcycle, motorcycleWithSideCar, motorscooter, tanker, trailer, van, anyVehicle)

    - Mandatory

requiredPermit : This attribute captures what permit(s) might be needed to park at this site. Semantics is that at least *one of* these permits is needed to park. When a permit is composed by more than one item (and) they can be combined with a ",". For instance "residentPermit,disabledPermit" stays that both, at the same time, a resident and a disabled permit are needed to park. If the list is empty no permit is needed.

- Attribute type: Property. List of **Text**
- Allowed values: The following, defined by the *PermitTypeEnum* enumeration of DATEX II version 2.3.
    - one Of (employeePermit, studentPermit, fairPermit, governmentPermit, residentPermit,specificIdentifiedVehiclePermit, visitorPermit, noPermitNeeded)
    - Any other application-specific
- Mandatory

openingHours : Opening hours of the parking site.

- Normative references: **http://schema.org/openingHours**
- Optional

maximumParkingDuration : Maximum allowed stay at site, on a general basis, encoded as a ISO8601 duration. An empty value or when non present indicates an indefinite duration.

- Attribute type: Property. **Text**
- Optional

chargeType : Type(s) of charge performed by the parking site.

- Attribute type: Property. List of **Text**
- Allowed values: Some of those defined by the DATEX II version 2.3 _ ChargeTypeEnum_ enumeration:
    - (flat, minimum, maximum, additionalIntervalPrice seasonTicket temporaryPrice firstIntervalPrice,annualPayment, monthlyPayment, free, other)
    - Any other application-specific
- Mandatory

priceRatePerMinute : Price rate per minute.

- Attribute type: Property. **Number**
- Optional

priceCurrency : Price currency of price rate per minute.

- Attribute type: Property. **Text**
- Normative references: **https://schema.org/priceCurrency**
- Optional

acceptedPaymentMethod : Accepted payment method(s).

- Normative references: **https://schema.org/acceptedPaymentMethod**
- Optional

usageScenario : Usage scenario(s). Gives more details to the category attribute.

- Attribute type: Property. List of **Text**
- Allowed values: Those defined by the enumeration *ParkingUsageScenarioEnum* of DATEX II version 2.3:
    - (truckParking, parkAndRide, parkAndCycle, parkAndWalk, kissAndRide, liftshare, carSharing, restArea, serviceArea, dropOffWithValet, dropOffMechanical, eventParking, automaticParkingGuidance, staffGuidesToSpace, vehicleLift, loadingBay, dropOff, overnightParking, other)
    - Or any other value useful for the application and not covered above.
- Optional

totalSpotNumber : The total number of spots offered by this parking site. This number can be difficult to be obtained for those parking locations on which spots are not clearly marked by lines.

- Attribute type: Property. **Number**
- Allowed values: Any positive integer number or 0.
    - Normative references: DATEX 2 version 2.3 attribute *parkingNumberOfSpaces* of the *ParkingRecord* class.
- Optional

availableSpotNumber : The number of spots available (*including* all vehicle types or reserved spaces, such as those for disabled people, long term parkers and so on). This might be harder to estimate at those parking locations on which spots borders are not clearly marked by lines.

- Attribute type: Property. **Number**
- Allowed values: A positive integer number, including 0. It must lower or equal than totalSpotNumber.
- Metadata:
    - timestamp : Timestamp of the last attribute update
    - Type: **DateTime**
- Optional

measuresPeriod : The measures period related to availableSpotNumber and priceRatePerMinute.

- Attribute type: Property. **Number**
- Optional

measuresPeriodUnit : The measures period unit related to availableSpotNumber and priceRatePerMinute.

- Attribute type: Property. **unitText**
- Optional

extraSpotNumber : The number of extra spots *available*, i.e. free. This value must aggregate free spots from all groups mentioned below: A/ Those reserved for special purposes and usually require a permit. Permit details will be found at parking group level (entity of type ParkingGroup). B/ Those reserved for other vehicle types different than the principal allowed vehicle type. C/ Any other group of parking spots not subject to the general condition rules conveyed by this entity.

- Attribute type: Property. **Number**
- Allowed values: A positive integer number, including 0.
- Metadata:
  - timestamp : Timestamp of the last attribute update
  - Type: **DateTime**
- Optional

occupancyDetectionType : Occupancy detection method(s).

- Attribute type: Property. List of **Text**
- Allowed values: The following from DATEX II version 2.3 _ OccupancyDetectionTypeEnum_:
  - (none, balancing, singleSpaceDetection, modelBased, manual)
  - Or any other application-specific
- Mandatory

parkingMode : Parking mode(s).

- Attribute type: Property. List of **Text**
- Allowed values: Those defined by the DATEX II version 2.3 *ParkingModeEnum* enumeration:
  - (perpendicularParking, parallelParking, echelonParking)
- Optional

averageSpotWidth : The average width of parking spots.

- Attribute type: Property. **Number**
- Default unit: Meters
- Optional

averageSpotLength : The average length of parking spots.

- Attribute type: Property. **Number**
- Default unit: Meters
- Optional

maximumAllowedHeight : Maximum allowed height for vehicles. If there are multiple zones, it will be the minimum height of all the zones.

- Attribute type: Property. **Number**
- Default unit: Meters
- Optional

maximumAllowedWidth : Maximum allowed width for vehicles. If there are multiple zones, it will be the minimum width of all the zones.

- Attribute type: Property. **Number**
- Default unit: Meters
- Optional

layout : Parking layout. Gives more details to the category attribute.

- Attribute type: Property. **Text**
- Allowed values: As per the *ParkingLayoutEnum* of DATEX II version 2.3:
  - one Of (automatedParkingGarage, surface, multiStorey, singleLevel, multiLevel, openSpace, covered, nested, field, rooftop, sheds, carports, garageBoxes, other). See also **OpenStreetMap**.
  - Or any other value useful for the application and not covered above.
- Optional

facilities : Facilities provided by this parking site.

- Attributes: List of **Text**
- Allowed values: The following defined by the *EquipmentTypeEnum* enumeration of DATEX II version 2.3:
  - (toilet, shower, informationPoint, internetWireless, payDesk, paymentMachine, cashMachine, vendingMachine, faxMachineOrService, copyMachineOrService, safeDeposit, luggageLocker, publicPhone, elevator, dumpingStation freshWater, wasteDisposal, refuseBin, iceFreeScaffold, playground, electricChargingStation, bikeParking, tollTerminal, defibrillator, firstAidEquipment fireHosefireExtinguisher fireHydrant)
  - Any other application-specific
- Optional

security : Security aspects provided by this parking site.

- Attributes: List of **Text**
- Allowed values: The following, some of them, defined by *ParkingSecurityEnum* of DATEX II version 2.3:
  - (patrolled, securityStaff, externalSecurity, cctv, dog, guard24hours, lighting, floodLight, fencesareaSeperatedFromSurroundings)
  - Any other application-specific
- Optional

highestFloor : For parking sites with multiple floor levels, highest floor.

- Attribute type: Property. **Number**
- Allowed values: An integer number. 0 is ground level. Upper floors are positive numbers. Lower floors are negative ones.
- Optional

lowestFloor : For parking sites with multiple floor levels, lowest floor.

- Attribute type: Property. **Number**

- Allowed values: An integer number.
- Optional

firstAvailableFloor : Number of the floor closest to the ground which currently has available parking spots.

- Attribute type: Property. **Number**
- Metadata:
  - timestamp : Timestamp of the last attribute update
  - Type: **DateTime**
- Allowed values: Stories are numbered between -n and n, being 0 ground floor.
- Optional

specialLocation : If the parking site is at a special location (airport, depatment store, etc.) it conveys what is such special location.

- Attribute type: Property. **Text**
- Allowed values: Those defined by *ParkingSpecialLocationEnum* of **DATEX II version 2.3**: (airportTerminal, exhibitonCentre, shoppingCentre, specificFacility, trainStation, campground, themePark, ferryTerminal, vehicleOnRailTerminal, coachStation, cableCarStation, publicTransportStation, market, religiousCentre, conventionCentre, cinema, skilift, hotel, other)
- Optional

reservationType : Conditions for reservation.

- Attribute type: Property. **Text**
- Allowed values: The following specified by *ReservationTypeEnum* of DATEX II version 2.3:
  - one Of (optional, mandatory, notAvailable, partly).
- Optional

owner : Parking site's owner.

- Attribute type: Property. List of **Text** or List of URIs
- Optional

provider : Parking site service provider.

- Attribute Type: Property. **Provider**
- Normative references: **https://schema.org/provider**
- Optional

contactPoint : Parking site contact point.

- Normative references: **https://schema.org/contactPoint**
- Optional

refParkingAccess : Parking site's access point(s).

- Attribute type: Property. List of references to **ParkingAccess**
- Optional

refParkingSpot : Individual parking spots belonging to this offstreet parking site.

- Attribute type: Relationship. List of references to **ParkingSpot**
- Optional

refParkingGroup : Parking site's identified group(s). A group can correspond to a zone, a complete storey, a group of spots, etc.

- Attribute type: Relationship. List of references to **ParkingGroup**
- Optional

areaServed : Area served by this parking site. Precise semantics can depend on the application or target city. For instance, it can be a neighbourhood, burough or district.

- Attribute type: Property. **Text**
- Optional

aggregateRating : Aggregated rating for this parking site.

- Normative References: **https://schema.org/aggregateRating**
- Optional

The example of the RestAPI result as per the data model defined can be shown as below:

```
{
  "id": "santander:daoiz_velarde_1_5",
  "type": "OnStreetParking",
  "category": {
    "value": [
      "blueZone",
      "shortTerm",
      "forDisabled"
    ]
  },
  "permitActiveHours": {
    "value": {
      "blueZonePermit": "Mo, Tu, We, Th, Fr, Sa 09:00-20:00"
    }
  },
  "requiredPermit": {
    "value": [
      "blueZonePermit",
      "disabledPermit"
    ]
  },
  "allowedVehicleType": {
    "value": "car"
  },
  "chargeType": {
    "value": [
      "temporaryFee"
    ]
  },
  "refParkingGroup": {
    "type": "Relationship",
    "value": [
      "daoiz-velarde-1-5-main",
      "daoiz-velarde-1-5-disabled"
    ]
  },
  "totalSpotNumber": {
    "value": 6
  },
  "location": {
    "type": "geo:json",
    "value": {
      "type": "Polygon",
      "coordinates": [
        [
          [
            -3.80356167695194,
            43.46296641666926
          ],
```