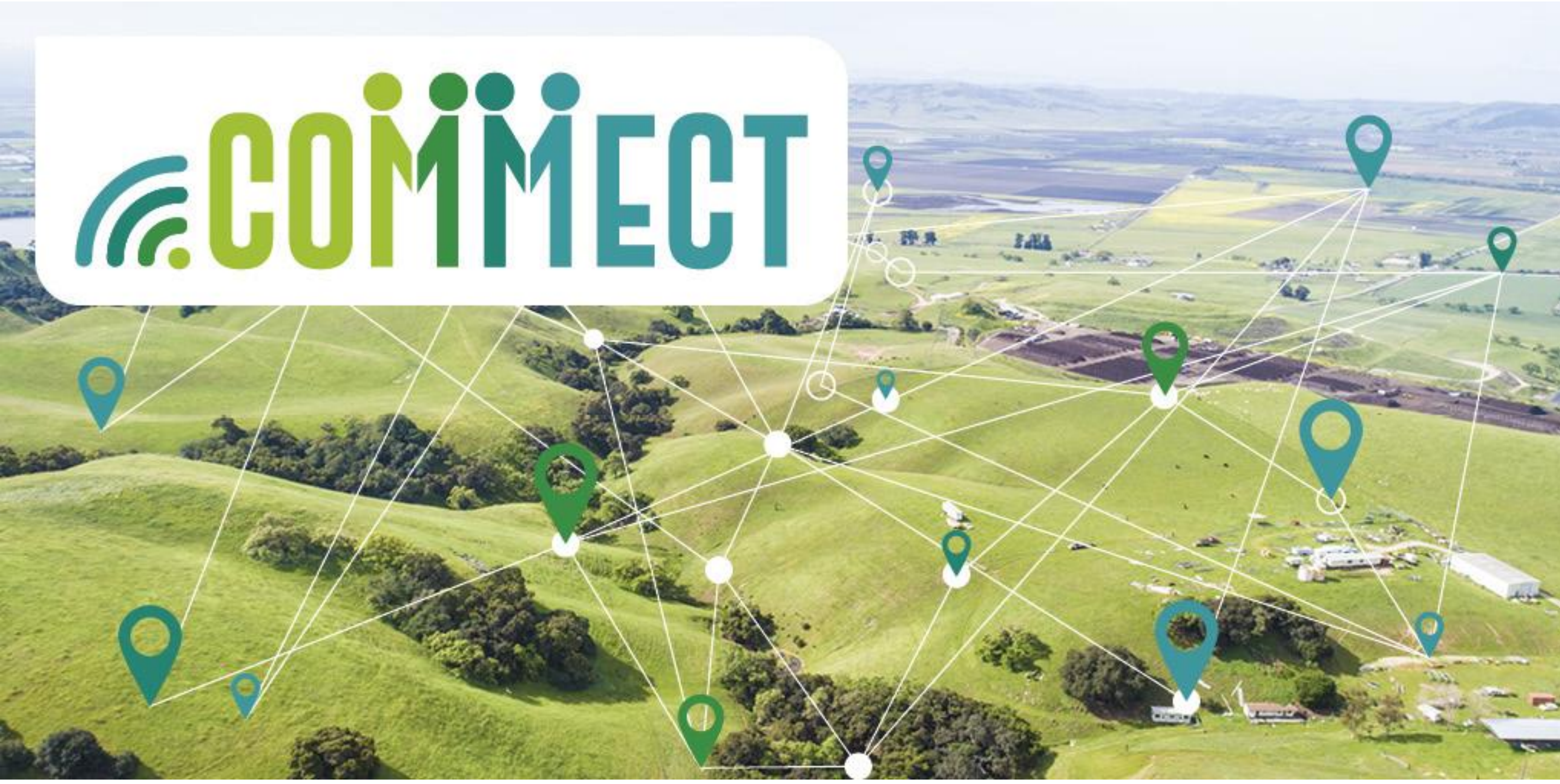
Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions



Deliverable 5.2

Report on Technical Validation in the Living Labs – Version 1

February 2024

PUBLIC

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COMMECT

Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions

Grant agreement No. 101060881

Report on Technical Validation in the Living Labs – Version 1

WP5 Validation of COMMECT Solutions

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COMMECT Project Abstract

Over the last years, the importance and need for broadband and high-speed connectivity has constantly increased. The Covid-19 pandemic has even accelerated this process towards a more connected society. But this holds mainly true for urban communities. In Europe a 13% lack access persists, and mainly concerns the most rural and remote areas. Those are the most challenging to address since they are the least commercially attractive. COMMECT aims at **bridging the digital divide**, by providing quality, reliable, and secure access for all in rural and remote areas. The **goal of extending broadband connectivity in rural and remote areas** will be achieved by *integrating Non-Terrestrial Networks with terrestrial cellular XG networks, and low-cost Internet of Things (IoT). Artificial Intelligence, Edge and Network Automation will reduce energy consumption both at connectivity and computing level.*

Participatory approach with end-users and ICT experts working together on development challenges will be the key **for the digitalization of the sector**. To ensure the rich exchange of best-practice and technical knowledge among the actors of the agro-forest value chain, COMMECT will set up **five Living Labs across and outside Europe**, *where end-users "pain" and (connectivity) "gains" will be largely discussed, from different perspectives.*

COMMECT aims at contributing to a balanced territorial development of the EU's rural areas and their communities by making smart agriculture and forest services accessible to all. COMMECT will facilitate that, by developing a **decision-making support tool** able to advise on the best connectivity solution, according to technical, socio-economic, and environmental considerations. This tool, incorporating collaborative business models, will be a *key enabler for jobs, business, and investment in rural areas, as well as for improving the quality of life in areas such as healthcare, education, e-government, among others.*

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Executive Summary

The COMMECT project aims at bridging the existing digital divide in rural areas by addressing the needs for digitalization in rural communities with cost-effective and environmental-friendly connectivity solutions. To that end, the COMMECT project will investigate the suitability of existing solutions and their combination to fulfil the end-users' needs by meeting the requirements of the different use cases that have been identified in deliverables *D1.1 – Report on end-users' needs and relevant use cases* [1] and *D1.2 – Report on COMMECT Requirements and KPIs* [2].

This document is the first version of the report on technical validation of the COMMECT solutions, which will be performed through real-world experimentation and live trials conducted within the five Living Labs (LL), for the selected use cases, among those identified in Work Package 1 (WP1).

The assessment of connectivity solutions will be performed by comparing the obtained results with the target requirements outlined in deliverable D1.2 [2]. The technical results, post-processed for clarity and relevance, will serve as inputs for the development and maintenance of the Decision-Making Support Tool (DST) envisaged in task T3.4. The Key Performance Indicators (KPIs) evaluation will assist in selecting the most appropriate connectivity solution based on the use case requirements, technology availability, etc. Furthermore, they will contribute to formulate COMMECT deployment guidelines and identifying potential system enhancements, thereby providing valuable feedback to the COMMECT architecture, addressed in deliverable *D1.3 – COMMECT Solution architecture, version 1* [3].

It is important to note that the connectivity solutions for the five LLs have been designed by M18, following the COMMECT Work Plan, and one of the Grant Agreement (GA) milestones (ML4). However, their current deployment in the field (i.e., in the LLs) is at different stages of advancement, as already documented in deliverable *D4.1 – Set-up and Design of Living Labs* [4]. This deliverable can be considered as a follow-up of D4.1, which presents further activities, implemented from M15 until M18. Clear strategy for performing technical requirements evaluation in the LLs is presented, while concrete results will be presented in the last version of this deliverable, specifically in deliverable *D5.4 – Report on Technical Validation in the Living Labs, version 2* [5], due in June 2025 (M34).

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Glossary of Terms

3GPP	3rd Generation Partnership Project
5G NR	5G New Radio
5G NSA	5G Non-Standalone
5G SA	5G Standalone
AI	Artificial Intelligence
BLE	Bluetooth Low Energy
DL	Downlink
DST	Decision-making Support Tool
eMTC	enhanced Machine-Type Communication
EO	Earth Observation
FDD	Frequency-Division Duplexing
HSPA	High-Speed Packet Access
IAQ	Indoor Air Quality
ICT	Information and Communication Technology
IoT	Internet of Things
KPI	Key Performance Indicator
LL	Living Lab
LoRaWAN	Long Range Wide Area Networks
LTE	Long-Term Evolution
MCX	Mission-Critical Services
ML	Machine Learning
NB-IoT	NarrowBand IoT
NoW	Network on Wheels
NDVI	Normalized Difference Vegetation Index
PDR	Packet Delivery Ratio
RTT	Round-Trip Time
RXRM	Real-time eXtended Reality Multimedia
SF	Spreading Factor
SLA	Service Level Agreement
TDD	Time-Division Duplexing
UAV	Unmanned Aerial Vehicle
UC	Use Case
UL	Uplink
WP	Work Package

1. Introduction

The main goal of the COMMECT project is to address the digital gap existing in rural areas. This initiative aims to propose and assess the performance of a set of connectivity solutions tailored to specific use cases that have been identified for the different COMMECT Living Labs (LLs). WP5 coordinates the validation of the COMMECT system and connectivity solutions from a technical, socio-economic, and environmental point of view.

According to the COMMECT methodology and work plan, the partners will initially evaluate these proposed solutions in a controlled environment, as previously described in deliverable *D5.1 – Technical Performance of COMMECT solutions, version 1* [6].

Following the performance assessment in a controlled environment, the next phase is the deployment of the connectivity solutions in the LLs, previously explained in deliverable D4.1 [4]. And lastly, the technical validation of these solutions is performed, a work that is carried out in task T5.2. This task encompasses the real-world experimentation and live trials performed in each of the five COMMECT LLs.

1.1. Document Objectives

This document outlines the deployment of the connectivity solutions in the LLs, with the aim of testing the achievable performance, against the technical KPIs defined in deliverable D1.2 [2]. Considering the status of deployment, the deliverable focuses on current in-field activities, and on the test and validation plans which will be performed in the coming months once the implementation of the connectivity solutions in the LLs will be finalized.

1.2. Link to other Work Packages

WP5 strongly relies on the actual deployments in the LLs (WP4). It will coordinate and validate the performance of the COMMECT connectivity solutions proposed in WP2, specifically addressing the use cases outlined in WP1. This document focuses on the technical performance assessment of individual COMMECT connectivity solutions under operational conditions in the LLs established in WP4, defined within task T4.1 and described in deliverable D4.1 [4].

In addition to verifying that the technical requirements defined in task T1.2 are met in the LLs, the post-processed technical results from this task will serve as valuable input for the Decision-making Support Tool (DST) in task T3.4 (WP3). The data collected from performance evaluations of the connectivity solutions in both a controlled environment (T5.1) and the LLs (T5.2) will be fed to the DST. While the first set of data is valuable input, using the results of the performance evaluation in the LLs is considered more relevant due to its basis on actual conditions.

Furthermore, the outcomes of this task will contribute to developing the COMMECT deployment guidelines and identifying potential system architecture enhancements in task T1.3 (WP1).

1.3. Structure of the Document

The structure of this document is as follows: Section 2 summarizes the methodology adopted for the Technical Validation, including testing conditions. In Section 3, validation strategies for each LL are individually outlined. Each LL details deployment and test plans on a use case basis. Section 4 presents the insights and conclusions derived, at the time of the submission of this document.

2. Methodology for Technical Validation in the Living Labs

This section outlines the methodology adopted by COMMECT for performing the technical validation of the proposed connectivity solutions in the Living Labs. The testing conditions are also described, with an outlook on how they are representative and reproducible in other LLs, in different regions, countries, when applied to similar or different use cases.

Though the solutions proposed by COMMECT are not a product or to be sold, we have decided to base on a pseudo-V-model to technically validate our solutions deployed in the LL, i.e. unit testing, integration testing, system testing and performance testing.

Unit testing is performed for each of the components purchased or developed (IoT devices, sensors, terminals, software tools, etc.) to validate that the components function as expected. This validation has been done during COMMECT, previously or in parallel if the components have already been used by partners in other projects.

Integration testing is performed when the components of a LL are combined and tested as a group. The integration is performed in terms of software, hardware and networking infrastructure. Again, this integration might have been done in other projects but the main integration testing is performed within COMMECT.

System testing is performed after the deployment of the connectivity solutions in the Living Labs (WP4), as well as the equipment necessary to perform the connectivity tests. This equipment consists of both hardware (e.g., antennas, sensors, base stations) and software (e.g. monitoring tools). This testing is performed in an environment that closely mirrors the LL or in the LL.

Finally, performance testing is focused on evaluating the connectivity solutions in the LLs in terms of the KPIs discussed in deliverable D1.2. This phase is specific to COMMECT and is described in detail below.

2.1. Performance Validation

Once the connectivity technologies are up and running in the LLs, data collection is continuous monitored over long periods of time (hours to weeks) to create a statistically consistent database. Due to the heterogeneous nature of each Living Lab, multiple data of different nature are collected. Among others:

a. Soil (temperature, moisture, conductivity) and weather (air temperature, humidity, precipitation) data conditions in several type of fields, e.g., vineyards and olive crops.
b. Satellite data and images in vineyards.
c. Video streams for digitalised management of vineyards, and remote operational support in forests.
d. Drones images for seamless monitoring of the forest.
e. Data related to Quality of Service (QoS) metrics, like throughput, latency, packet losses, etc. This data allows to validate if the connectivity solutions fulfil the requirements of the envisaged services/applications, e.g., data streaming for monitoring livestock transport and license-plate recognition in farms.

The acquired data is analyzed and post-processed to determine the effectiveness of the connectivity solution in terms of multiple Key Performance Indicators (KPIs). It is crucial to determine whether the proposed connectivity solutions are capable of reliably transmitting the data described above. For this purpose, KPIs are analyzed such as:

- Uplink throughput: It determines the effectiveness of connectivity solutions for sending data over the network.
- Downlink throughput: It determines the effectiveness of connectivity solutions for receiving data over the network.
- Service reliability: It quantifies the reliability of the network in terms of the data percentage that is successfully sent throughout the network.
- Latency: It measures the delay of the data to be sent over the network. This parameter can be crucial for real-time applications. Latency can also be used to quantify the reliability of the network since very high delays are indicative of packet loss in the network as retransmission becomes necessary. Finally, latency can also limit the throughput of TCP-based services and might reduce the optimal usage of the connectivity solutions, especially when latency is combined with losses.

Finally, this evaluation quantitatively defines the effectiveness of each solution in serving the needs of stakeholders and end users.

Regarding the testing conditions, the five Living Labs deployed across Europe provide a variety of scenarios and environments which are representative of many of the connectivity challenges in rural areas. Therefore, each Living Lab is equipped with several and different connectivity solutions and network infrastructures to test their performance under several conditions. The representativeness of a wide span of testing conditions is shown from several perspectives:

- Network availability: The tests are conducted in areas with different levels of network availability, ranging from well-connected regions to remote locations with limited or no network coverage. This allows us to evaluate the performance of connectivity solutions in both optimal and challenging environments.
- Networks integration: Different technologies are integrated in COMMECT for responding to end user needs, including XG, 5G private networks, Internet of Things (IoT), Non-Terrestrial Networks (satellite and Unmanned Aerial Vehicles) and Wi-Fi networks. These technologies are integrated and tested as part of a backhauling network or propose multiple link choices. The diversity of technologies and type of integrations help to understand how each technology affects the performance and reliability of connectivity solutions in rural deployments.
- Representativeness of scenarios and environmental conditions: The different Living Labs cover multiple aspects of work tasks related to the agricultural, forestry and livestock sectors in rural communities. Thus, these Living Labs encompass a wide range of scenarios, being representative of several conditions to which end users in the rural community may be exposed. Mobility conditions are also addressed in the case of livestock transport and for different countries.
- Types of applications: Different types of services are transmitted during the tests depending on the target use case, both narrowband and broadband. The transmitted data includes for example large volumes of sensor data, high-resolution video streams, interactive services and real-time communication data. This heterogeneity on the transmitted data allows us to assess how well the connectivity solutions handle diverse end user applications and services needed in the LLs.

By considering these technical aspects, the testing conditions provide a comprehensive assessment of the performance and reliability of connectivity solutions in rural environments. The insights obtained from these tests will allow us to assess that the proposed solutions are robust and effective across a wide range of scenarios representative of rural communities in Europe.

3. Plan for the Technical Validation of COMMECT Connectivity Solutions

3.1. LL N.1 – Luxembourg – Digitalisation of Viticulture

Viticulture is one of the most important agricultural activities in Luxembourg. However, climate change has an unprecedented impact on winegrowers' lives. Disease severities (Downy Mildew fungus) and drought stress have significant threat on the overall crop. In this context, LL Luxembourg is investigating different connectivity technologies and developing digital tools to help winegrowers address their needs in controlling diseases, dealing with drought stress and fertilization, and monitoring the vineyard through crop, plant, and leaf inventory.

Two use cases have been identified to support farmers protect plants and improve crops. The first use case, UC1.1, provides winegrowers with decisional data supporting in irrigation, fertilization, and pesticide management through the deployment of a wireless network for "In-Field Microclimate and Crop Monitoring in Vineyards". The second use case, UC1.2, provides a digital inventory of the vineyard through the creation of a "Digital Twin for Digitalized Management of Vineyards".

3.1.1 UC 1.1 – In-Field Microclimate and Crop Monitoring in Vineyards

The monitoring of micro-climate conditions has great potential for the prediction of disease spread and thus plant protection. Continuous analysis of local meteorological data, soil moisture and leaf wetness help to detect infections and spread of Downy Mildew fungus in the field, and support winegrowers in decision-making related to timing, dosing, and treatment for disease control.

In the LL Luxembourg several soil sensors and weather stations were deployed in the field to monitor soil and weather conditions (see deliverable D4.1 [4]). A combination of IoT (LoRa), and cellular technologies (3G/4G) were selected for transmitting the data, depending on communication performances and available connectivity solutions in the deployment area.

Most of the Luxembourgish vineyards are located in the Moselle region. The core of the LL "*Digitalisation of Viticulture*" is in Remich, at the experimental fields, offered by the Wine Institute IVV (or Institut Viti-Vincole). Thanks to the engagement of several end-users (winegrowers in the region), the LL has been extended in the private vineyards, along the Moselle Valley. At IVV, a local Long Range Wide Area Network (LoRaWAN) was created to provide connectivity to four weather stations installed in an agro-forest Pilot, for long term monitoring of potential impact of tree vegetations on vineyards, in period of water stress. LoRa is a cost effective and low energy solution: a single gateway can collect data from several devices (e.g. weather station) in its range, while keeping the energy consumption low on the end devices. However, along the Moselle Valley, the six IoT devices (4 soil sensors and 2 weather stations) were distributed along a line of 30 km, and it was not efficient to deploy several gateways. Thus, it was decided to simply use the cellular XG network (mainly 3G/4G) to send Internet of Things (IoT) data.

Deployment Strategy

After the identification of the deployment positions of each sensor or weather station (see deliverable D4.1), the communication technology was selected based on two main complementary criteria: network availability and network density.

A first batch of deployment was identified with 4 full meteorological stations and 4 soil sensors to be deployed in the same vines field near the plants (Figure 1: left, green Icons). In each position (green Icon), a full meteorological station and soil sensor are installed. These stations can be identified as "sensors network" that can be covered with one gateway (Figure 1: left, green tower). For this, LoRaWAN connectivity was selected for these devices.

A second batch of deployment was identified with two full weather stations (dark blue) and four leaf wetness sensors (blue) to be deployed along the Moselle valley (Figure 1: right). The positions were distributed from north to south over a 30km line and all the positions were covered by the network operator. Therefore, the cellular XG network was selected for this batch of deployment.

Figure 1. Deployment locations for UC1.1.

The LL Luxembourg followed a deployment strategy starting with preliminary surveys of the field to identify the deployment positions and evaluate accessibility to network and electricity. This step is followed by a test of the devices in the lab before going to the field for installation.

The first installation with a LoRaWAN infrastructure was deployed in the period of M11-M16, in the field in Remich with the support of IVV. The second installation of sensors and weather stations with XG technology has been deployed during M16-M17. Table 1 shows the timeline for the deployment steps of UC1.1 in the LL.

Table 1. Time plan for the deployments of UC1.1.

Month	Description
M11 (July 2023)	IVV Remich field survey
M14 (October 2023)	Installation of LoRaWAN gateway in Remich
M15 (November 2023)	Installation of LoRaWAN weather stations and sensors in Remich
M16 (December 2023)	Field survey for Installation of XG weather stations and sensors
M17 (January 2024)	Installation of XG weather stations and sensors

Tests and Validation

To bring connectivity to the unconnected regions, LL Luxembourg identified 3G/4G and LoRaWAN as access communication technologies to send sensors data. It is worth mentioning that the selected platform from Lumbara[1] implements another security layer on top of LoRaWAN security. Data exchange between devices and the LoRa server is encrypted. Data is forwarded to the Lumbara Bridge IoT handover, where the payload is decoded. Then the bridge processes and send the data to agri.lumbara (the platform that allows data visualization). To validate the deployments, a set of technical requirements will be used to measure the efficiency of the communication platform in the real environment.

The devices deployed in the field are battery powered; limited in terms of energy. The periodical data transmission should be then efficient. For this, a threshold for Packet Delivery Ratio (PDR) and battery lifetime were fixed in deliverable D1.2 [2] to validate the sensor data transmission for the access network.

For LoRaWAN networks, the gateway is responsible for data forwarding to remote servers via a backhauling network (XG in the UC1.1 deployment). To achieve a proper and timely data forwarding, a threshold for backhauling network availability and latency should be respected.

Technical Requirements

After the successful deployment of devices and communication platform, following the steps described in the previous section, data is continuously sent from devices in the field to the server. Collected data is analysed at the server level to check missing packets, battery level or gateway disconnection.

- PDR evaluation:
  Devices are programmed to send data periodically. For this period of test, all the sensors deployed in the field are programmed to send a packet every 1 hour. Analysing the received packets over a period of deployment will determine the PDR. The PDR can be calculated using the following formula, where nRX is the number of received packets and nRX0 is the number of expected packets during the same period:

$$\text{PDR} = \frac{nRX}{nRX0}$$

- Battery lifetime:
  All the devices deployed in the field are equipped with solar panels and rechargeable batteries to insure power availability in all the periods of the day. The devices also send information about the battery level, that can be monitored through the platform.

- Network availability:
  The LoRaWAN gateway is connected to the servers using a cellular network. The network availability can be calculated as the sum of the periods the gateway was disconnected from the server (ΔT_off) over the test period (ΔT_test). The gateway is powered with the main power supply and the only reason for disconnection is the backhauling network availability. Information about gateway disconnection can be found at the LoRa server level.

$$\text{Na} = \frac{\sum \Delta\text{T\_off}}{\Delta\text{T\_test}}$$

- Latency:
  In the deployment of UC1.1, the LL selected the cellular network for the backhauling. The network latency is dependent on the operator. However, to measure the latency,

[1] https://lumbara.com/en/lumbara_base

we can create an access point from the gateway, connect a laptop to the local network and measure latency using the *Ping* tool.

Preliminary Results

In the following, we provide some preliminary results for a test of LoRaWAN devices over 60 days for the period from 14th December 2023 to 11th February 2024.

For this period of test, the devices were configured to send data packets every hour to the server. The devices wake up periodically to collect measurements and send data packets before switching to sleep mode to save energy. The periodicity of data collection and transfer can be configured to meet the application requirements (the VitiMeteo App from GeoSens to predict Downy Mildew infection).

The transmission parameters, i.e. Spreading Factor (SF) and transmission power (Tx), are preconfigured by the device provider but can be changed if the performance test results do not meet the requirements identified previously.

- PDR Evaluation:
  Devices are programmed to send data every 1 hour. For this period of 60 days, it is expected to receive 5760 packets of data while only 5742 packets were received. The PDR during this test is equal to 99.68%, which is respecting the target value of 90%.
- Battery lifetime:
  Figure 2 shows the evolution of the battery level for the 4 devices installed in the field. The plots show that the battery is recharged the following day and never drops below 7.9 V, which fulfils the requirement of 1-year lasting batteries. However, the validation of this metric can be confirmed in the next version of this deliverable, where the energy consumption will be tested over a longer period.

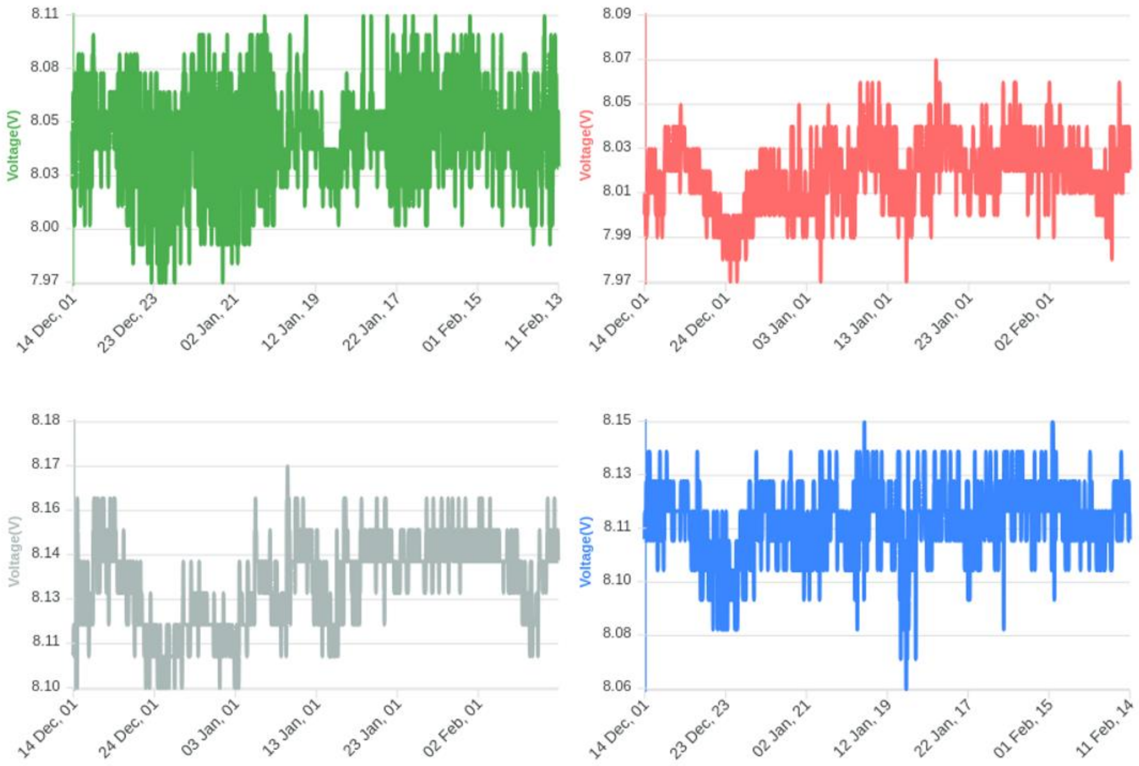

Figure 2. Battery level of the devices in field.

- Backhauling network:
  As mentioned before, this deployment relies on the network operator for the backhauling part. The gateway was never disconnected during this test period.

3.1.2 UC 1.2 – Digital Twin for Digitalised Management of Vineyards

The digital inventory of the vineyard is an essential tool to rapidly detect diseases, diagnose plants and predict and advise farmers on field activities, at macro and micro scales. A full digital representation of the vine in its Digital Twin will be realized with continuous collection of data from the field.

In this use case, the LL will focus on Earth Observation (EO) data and images collected at different scales. From a regional perspective, satellite data, like Sentinel-2, will be processed frequently to detect drought stress and sunburns. From a bird eye perspective, Unmanned Aerial Vehicles (UAVs) will be used to collect image data at canopy level, to detect patterns and heterogeneities in the field. Finally, at a more precise scale, cameras will be mounted on tractors to collect video streams in parallel with the daily work of the farmers, these high-resolution images will allow an accurate representation of stems and leaves. For a further description of the deployment, the reader is referred to [4].

A connectivity platform is needed for this use case to send the video streams collected using cameras (from smartphone) on tractors, while they carry their daily work. The tractor, in parallel with his job navigating between the rows, will record videos of the plant. Consequently, the vine field should have a network coverage with enough bandwidth to upload videos, within the activity period.

Deployment Strategy

The deployment of this use case will be done in the vineyard at IVV premises in Remich. A Wi-Fi network will be deployed with the support of a satellite backhauling link offered by SES -the LL partner and satellite operator- using the smart gateway. The smart gateway has a Wi-Fi interface to create a local access network and a backhauling interface that will be connected to the satellite terminal. It will be deployed as a data forwarder to transfer data packets to the application server using the satellite backhaul. More details about the smart IoT Gateway and satellite backhauling are provided in deliverable D2.1 [7].

To ensure the coverage of the field and data upload within the farmers activity period, some repeaters might be deployed to extend the Wi-Fi network range. The gateway will collect video streams sent directly by the smartphone, or relayed via repeaters, and forward them to the server using the satellite backbone.

Different strategies for video uploading, repeaters deployment and picture resolutions will be tested in the field before identifying the best configuration of deployment. Depending on field tests and network performance parameters such as the Uplink (UL) throughput and communication range reached in the field (between the gateway, repeaters, and smartphone); it can be decided on the video size to be uploaded (resolution and records duration). The communication performances will decide also if some repeaters should be deployed along the rows, or if scheduling transmission when the tractor is approaching the gateway is enough for data upload.

A first field visit was organized (M17) to identify logistics coordination related to the deployment. With the support of IVV, the team identified a safe position for the installation of the smartphone on the tractor (see Figure 3), and a tentative plan for repeaters, gateway, and satellite terminal deployment.

Before the tests and installation on field, an end-to-end network deployment will be done at the laboratory to validate the infrastructure and equipment: video transmission using the smart Gateway and satellite terminal. After validation, a first deployment of the network in the field of Remich will be planned to test the communication range and design the final deployment: repeaters deployment, image resolution and transmission schedule. Table 2 summarizes the deployment steps of UC1.2.

Figure 3. Smartphone with GPS antenna to collect data, and tractor to carry the smartphone.

Table 2. Time plan for the deployments of UC1.2.

Month	Description
M17 (January 2024)	IVV Remich field survey
M18 – M19 (Feb – March)	Lab test of the communication platform
M20 – M22 (April – Jun)	Network deployment and field tests
M26 – M36 (Oct – end)	Final configuration, data collection and validation

Tests and Validation

To evaluate the performance of the connectivity solution that will be deployed in the field, the LL Luxembourg identified two requirements to guarantee video upload and provide winegrowers the processed data within the same day. The network deployment targets a minimum uplink throughput and a maximum delay of 5 Mbps and 400 ms, respectively.

Technical Requirements

The technical requirements will be evaluated during the lab tests and after the deployment in the field.

- UL throughput: The achievable UL throughput will be measured using an *IPerf* (a traffic generator tool) installed locally.
- Latency: The end-to-end latency of the network will be tested using the *Ping tool*.

3.2. LL N.2 – Norway – Connected Forestry

Norway's forestry sector plays a significant role in the country's economy and environmental stewardship. Norway boasts extensive forests covering approximately 33% of its total land area. These forests are predominantly composed of coniferous species, such as spruce and pine, and contribute to a thriving forestry industry. Sustainable forest management practices are integral to Norway's approach, ensuring the long-term health of the forests while supporting a range of economic activities. The sector not only provides timber and wood products but also contributes to biodiversity conservation, carbon sequestration, and recreational opportunities. Additionally, Norway's commitment to sustainable forestry aligns with its broader environmental policies, reflecting a balance between economic development and ecological responsibility.

Despite being one of Norway's oldest and largest industries, the forestry sector faces a notable challenge in terms of digitalization. The industry's value chain has yet to fully leverage technological advancements, particularly in terms of connectivity solutions. While sustainable forestry practices have been a cornerstone, the integration of digital tools for improved efficiency, resource management, and market connectivity remains an area of potential growth. As Norway continues to embrace innovation across various sectors, there is an opportunity for the forestry industry to enhance its resilience and sustainability by embracing digital transformation and staying abreast of technological advancements.

To address the existing gap in the digitalization of Norway's forestry sector, the COMMECT Norwegian LL has identified three specific use cases designed to optimize the industry's value chain. These initiatives target key areas such as resource management, operational efficiency, and market connectivity. By implementing these tailored solutions, COMMECT aims to propel the forestry sector into a new era of technological integration, fostering sustainable practices and positioning it to thrive in an increasingly interconnected and technologically advanced landscape.

3.2.1 UC 2.1 – Remote Operational Support from Expert for Forest Machine Operator

The forestry industry encounters a pressing need for remote assistance in thinning and logging activities, where on-site operators require immediate guidance and support. However, this necessity faces challenges due to the insufficient performance of cellular networks in forested areas. To address this issue, the proposed solution involves the deployment of local private 5G networks specifically designed for forestry environments. This infrastructure facilitates high-quality video transmissions from forest machinery to enable seamless remote support through online cameras. Experts from the forest operator's company could remotely advise and assist on-site operators in decision-making. Furthermore, the solution extends to addressing maintenance, detection, and repair of engine or machine errors, with a vendor's expert supervising operators through online cameras utilizing high-quality video feeds at the vendor's location. By addressing the critical need for immediate remote assistance and overcoming challenges posed by inadequate network performance, this comprehensive solution ensures efficient support for on-site operators in various forestry operations.

Deployment Strategy

The Living Lab in Norway will rely on the Network on Wheels "NoW" [8] to provide connectivity in "hard-to-cover" areas. The NoW will be responsible for establishing a private 5G Standalone (SA) network, that will be used to transmit real-time high-quality video for remote expert support.

As detailed in Deliverable D4.1 [4], number of solutions are in discussion to provide remote support to the operators via high resolution video streamed from the field. Nokia Real-time extended Reality Multimedia (RXRM) is one of the potential candidates. The solution offers immersive, real-time experiences that have the potential to reshape collaborative work dynamics between the remote expert and the field operators.

Nokia's Real-time extended Reality Multimedia (RXRM) [8] is poised to revolutionize remote support through video streams, significantly enhancing immersive, real-time experiences. This breakthrough technology is set to play a pivotal role in elevating the performance, well-being and safety of on-site operators within the forestry industry. By offering low latency, high resolutions, and reduced bandwidth requirements.

One of the standout features of RXRM lies in its ability to deliver immersive and high-quality content over existing networks without the need for expensive upgrades. The technology relies on a highly efficient RXRM media processor, which plays a crucial role in minimizing bandwidth requirements. This processor incorporates video and audio analytics, all powered by Artificial Intelligence (AI). The processing can be executed either on the forest machinery itself or locally at the NoW. The decompression operation is seamlessly carried out through the RXRM Media Viewer application. Figure 4 shows an example on a potential use case of RXRM.

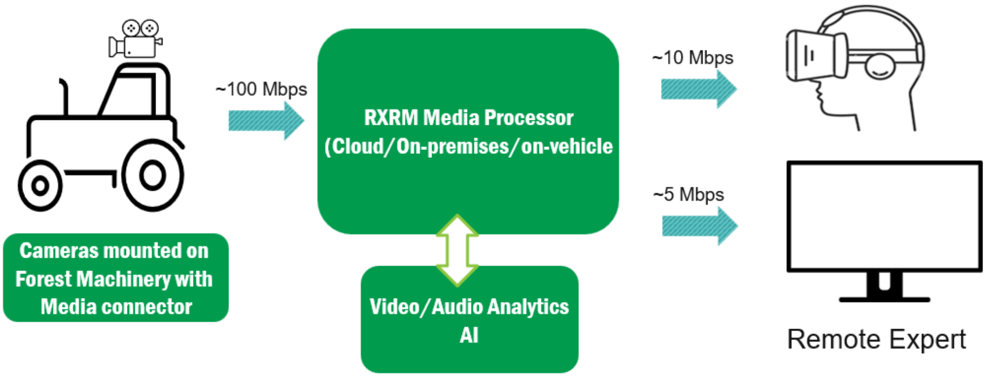

Figure 4. RXRM technology for remote support and operations [8].

RXRM plays a crucial role in remote supervision by enabling experts to assist multiple on-ground teams seamlessly from a central site. This empowerment of on-ground teams not only fosters increased efficiency but also elevates the overall effectiveness of the experts. Beyond remote supervision, RXRM showcases its versatility in various potential use cases, including teleoperation, enabling engineers to remotely operate machines, and situational awareness, providing operators with a comprehensive real-time understanding of on-field activities for informed decision-making.

Tests and Validation

UC2.1 is split in two parts, the first part focuses on providing the connectivity solution, whereas the second part focuses on providing the video solutions that can be mounted on the forestry machinery and streamed back to the remote experts. A portable connectivity solution (5G private network) is ready to be used, whereas the focus is now on finalizing and deploying the video streaming solutions for forestry machineries connected over a 5G private network.

As mentioned earlier, to support and deploy the video streaming solutions, the Norway LL is in dialogue with potential video streaming solution providers. Based on the outcomes of these discussions, a deployment and validation time plan was developed, which is shown in Table 3. The deployment strategy involves finalizing video streaming solutions in M18-M20, followed by the integration works on the forestry machinery. Finally end-to-end validation tests, trials and demos will be done to display the efficacy of the remote support use case to forestry stakeholders.

The deployment might slightly vary depending on the weather conditions and the progress on finalization of the video streaming solution.

Table 3. Time plan for the deployments of UC2.1.

Month	Description
M18 – M20	Evaluation of remote video streaming solutions
M20 – M25	Integration of the real-time video streaming solution with the forestry machinery
M23 – M24	End-to-end validation tests over 5G private network
M25 – M29	Trials and demonstrations

Technical Requirements

To evaluate the end-to-end performance, we will assess the technical requirements defined in deliverable D1.2 [2], indicating the performance of the connectivity solution utilized for video streaming purposes for remote expert support. Table 4 includes the technical requirements along with tools that will be used to evaluate them.

Table 4. Technical requirements to validate UC2.1.

Test ID	Test Description	Tools/service	Metrics
R2.1	Uplink throughput	*IPerf*/OpenSpeed Test	Mbps
R2.2	Latency	Ping	ms
R2.3	Reliability	*IPerf* (UDP mode)	[%]

In addition to the primary technical requirements, metrics such as latency and video resolution for the real-time video application can be measured. Live network KPIs will be collected using the Keysight HawkEye testing tool [9]. This tool enables active monitoring of network performance, facilitating real-time observation of measurements like real-time streaming verification, user experience tests, and IP network Service Level Agreement (SLA) compliance. These measurements are only accessible via the HawkEye dashboard.

For the NoW, an additional KPI to consider is 5G coverage, which can be measured by evaluating signal strength (in dBm) at specific positions. Identifying points where coverage is lost, allows for the measurement of coverage range (in km).

3.2.2 UC 2.2 – Complex Situation Awareness Services in the Forests

The escalating threat of forest fires, exacerbated by global warming, emphasizes the urgent requirement for an advanced monitoring and surveillance system in forested areas. Forests are susceptible to a range of emergencies, from wildfires and landslides to floods, necessitating a sophisticated solution to enhance safety for both the natural environment and emergency personnel, including police, ambulance services, fire departments, and volunteers. The existing landscape requires immediate reporting of incidents like fire such as fires through digital channels. Additionally, a comprehensive approach to provide real-time digital information during crucial forest situations, thereby mitigating the inherent risks associated with these incidents.

In response to these challenges, the connectivity solutions proposed for UC2.2 harness the power of drone technology alongside on-ground sensors to establish a complete monitoring and surveillance environment. The deployment of drones and sensors, allow for seamless monitoring of the forests and promptly notifying emergency personnel in the event of critical incidents. The primary focus is on leveraging advanced cameras mounted on drones to capture high-resolution, multispectral aerial images. These *images are streamed in real time over a private 5G network to an external edge server*. The integration of on-map analytics further enhances the ability to visualize forest metrics, ensuring an immediate and effective response to alarming changes, particularly in the case of forest fires.

Deployment Strategy

For a successful implementation of the use case, first several technologies are needed, second good coordination and use of the different technologies is required.

A successful implementation of the proposed connectivity solution necessitates the integration of several technologies. The NoW will play a crucial role in providing private 5G network coverage across forestry areas. Sensors deployed in the field will utilize Bluetooth or Wi-Fi connectivity to interface with the far-edge router. A drone, equipped with a high-resolution multispectral camera, will capture live images and videos of the forest, transmitting them over the 5G network to an edge server. Real-time processing of the data and analytics outputs will be conducted at the edge server, with results stored on the Edge cloud. This live monitoring and processing via drones empowers emergency personnel with real-time surveillance capabilities, enhancing their ability to respond promptly to forest threats.

To facilitate communication and immediate response, an MCX (Mission-Critical Applications) application will be deployed as over the top application and on the smartphones of emergency service teams. This setup ensures that notifications containing the location, type, and severity level of any identified threat are instantly relayed to the on-ground teams. The primary goal is to empower teams to proactively address threats, such as fires, in their preliminary stages, thereby saving lives and preserving forestry resources.

Tests and Validation

The suggested time plan for this use case is detailed in Table 5, where the Norway LL will execute two parallel and independent tracks: the deployment and implementation of sensors and drones for real-time surveillance, and the deployment of the push-to-talk application.

Table 5. Time plan for the deployments of UC2.2.

Month	Description
M15 – M20	AI model: data collection and training
M17 – M21	Test based sensor deployment and edge communication
M18 – M21	Deployment of MCX application
M20 – M22	Initial end-to-end validation tests
M23 – M25	Initial field trials
M25 – M29	Use case end-to-end experiment

Certain requirements for this use case align with those outlined in UC2.1, while others are unique to the distinctive features and goals of this scenario.

Technical Requirements

Latency will be measured from both a network perspective (i.e., the NoW) and an application perspective (MCX application). This dual approach during the test phase aims to cover latency considerations comprehensively. Table 6 outlines the detailed technical requirements for this use case, encompassing factors crucial for effective drone surveillance, data transmission, and timely communication with the emergency response teams.

By delineating these technical requirements, the Norway LL aims to establish a robust framework for evaluating the performance and efficiency of the proposed connectivity solution, ensuring that it meets the necessary benchmarks for seamless and timely forest monitoring and emergency response.

Table 6. Technical requirements for UC2.2 validation.

Test ID	Test Description	Tools/service	Metrics
R2.4	Uplink throughput	IPerf/ OpenSpeed Test	Mbps
R2.5	Latency	Ping	ms
R2.6	Service Reliability	*IPerf* (UDP mode)	[%]

Preliminary Results

During the past months, we started lab implementation of the solution by deploying sensors in a lab environment and visualizing the measurements on an online portal. Figure 5 shows the real-time observed test measurements from one of the sensors deployed on the field.

Figure 5. Real-time analytics as visualized on the portal.

The portal is still under development but once it is finished, the stakeholders will receive the credentials to authenticate so they can actively monitor the forest conditions.

A set of deep learning models is also under development. The initial model will be an image segmentation deep neural network, designed to perform precise image segmentation on each frame captured by the multispectral camera integrated on the UAV. This process involves dissecting the image frame into enclosed pixel areas (referred to as blobs) with consistent colour and texture attributes. The colour data of each identified segment can be used to compute the Normalized Difference Vegetation Index (NDVI), a metric crucial for assessing forest health. This segmentation model will be based on the widely adopted Mask RCNN paradigm used in RGB image segmentation. However, it will be fine-tuned with innovative unsupervised domain adaptation methods to effectively process aerial multispectral images. Figure 6 shows an example of the image segmentation to highlight the trees.

Figure 6. Computer vision model for tree counting.

3.2.3 UC 2.3 – Digital Decision Support for Forest Machine Operators

This use case builds upon the digital support frameworks established in UC2.1 and UC2.2, with a focus on enhancing the toolkit available to forest operators. It introduces advanced digital tools such as maps, applications, and live updates, leveraging the same connectivity and deployment strategies. This use case extends the application of drone technology from UC2.2 for aerial surveys. These surveys aim to create detailed digital representations of the forest, encompassing aspects like tree density and heights.

The collected data, coupled with information from ground sensors, will be seamlessly integrated into a mobile app. This integration is designed to provide a comprehensive monitoring solution, merging drone visuals and IoT data. The goal is to enable real-time oversight of forest conditions, furnishing forest operators with a powerful toolset for informed decision-making and proactive management.

Deployment Strategy

Since this use case builds upon the foundations laid by UC2.1 and UC2.2, it is employing the same innovative technologies to empower operators in making informed, secure, and efficient decisions through the synergies of 5G and AI.

Drones will play a leading role in this scenario, equipped with RGB and multispectral cameras. Aerial images captured by the drone's camera undergo analysis using AI and computer vision tools to determine the thickness of the forest. By combining this information, operators can identify the most viable areas of the forest for thinning, optimizing resource allocation. Continuous monitoring of forest health and conditions is made possible through IoT sensors deployed in the field.

The final objective is to combine all the information onto an interactive map, seamlessly integrated into a mobile application accessible to operators within the machinery. This platform will aid the operators in making well-informed decisions through the utilization of advanced technologies.

The timeline for this use case aligns with the previously defined schedules for UC2.2 and UC2.1, ensuring a cohesive and synchronized approach in the deployment and implementation of the proposed technologies.

3.3. LL N.3 – Denmark – Connected Livestock Transport

The primary focus of the Danish LL revolves around improving connectivity solutions for the livestock transport sector, specifically pigs. To uphold animal welfare standards throughout transportation, the European Union (EU) established regulations encapsulated in the Council Regulation (EC) 1/2005. These guidelines encourage the monitoring of specific parameters during transportation, including some onboard sensors in the trailer. Moreover, certain country-specific regulations, such as those imposed by Danish transport standards, mandate continuous reporting of the truck's location throughout the journey.

Discussions with various stakeholders involved in the livestock trading process indicate a consensus that this sector could benefit from increased digitalization in logistics, and automatization of certain processes, leading to enhanced cost-efficiency. Livestock transport companies envision a future where substantial amounts of data are shared seamlessly with transport centres and regulatory bodies, boosting safety and optimizing the trading process. However, the current limitations of cellular coverage on rural areas of some major transport routes in Europe, where farms or transport centres are situated, often hinder meeting these requirements and impede the digitalization of the livestock trading industry.

Based on the above, three different use cases will be addressed by the Danish LL. The first use case tackles the challenge of ensuring seamless connectivity for transport units as they navigate from the pick-up location to their destination. The remaining two use cases prioritize enhancing connectivity within farms and resting stables, aiming to automatize the trading process and optimize the loading/unloading of animals.

3.3.1 UC 3.1 – Monitoring of Livestock Transport Along Rural Routes

This use case targets the lack of connectivity along the main transport routes of Europe, essential for route optimization and seamless reporting of location and onboard sensor information to both regulatory databases and the fleet manager centre.

In addressing the challenge of poor or non-existent cellular coverage in rural areas experienced by livestock transport units, this use case explores last-mile network solutions to ensure reliability throughout the route.

The connectivity solution explored in this use case involves cellular-based multi-connectivity in two modes: single-operator and multi-operator. In the **single-operator multi-connectivity mode**, the objective is to investigate whether antenna diversity can enhance coverage for users along the route. This mode has shown effectiveness in previous studies within the context of Internet of Farming [10], albeit on a smaller scale. In the Danish LL, extensive testing of this solution on a larger scale is planned, particularly on the primary transport routes across Europe.

In the **multi-operator multi-connectivity mode**, the focus is on examining the benefits derived from being simultaneously connected to two different operators. While cell towers are sometimes shared between operators, this is not always the case. In instances where one operator experiences a coverage gap, the other may provide available coverage. Even when base stations from two operators are co-located, variables such as configuration parameters, antenna positioning, and other factors can influence the quality of the coverage provided.

Tests and Validation

To assess the connectivity solution described above, the Danish LL will use the Multi-Access Gateway (MAGW). This equipment consists of a Gateworks Newport 6404 single board computer [11] and two SIMCom 8380G-M2 cellular modems [12], each equipped with four antennas. Figure 7 illustrates the MAGW setup. The Gateworks Newport mini-PC is a high-performance single board computer designed for networking, featuring 4 mini-PCIe sockets, 5 Gigabit Ethernet Ports and USB 2.0/3.0. The SIMCom modems are multi-band 5G New Radio (NR) / Long-Term Evolution-Frequency-Division Duplexing (LTE-FDD) / LTE – Time-Division Duplexing (LTE-TDD) / High Speed Packet Access+ (HSPA+) modules supporting 3GPP Release-16 5G NSA/SA. The modems will be equipped with two SIM cards, sourced from either the same operator or different operators. The selection depends on whether the testing involves the single-operator multi-connectivity mode or the multi-operator multi-connectivity mode, respectively.

Figure 7. Multi-Access Gateway (MAGW).

Additionally, the MAGW is equipped with *mpconn* [13], a software tool developed by researchers at Aalborg University. This tool allows to perform multi-connectivity through packet duplication across multiple network interfaces, creating a tunnel at either Layer 2 (Ethernet over transport layer) or Layer 3 (IP over transport layer). The tool currently offers two different duplication strategies:

- Blind duplication, where all incoming packets or data streams are duplicated through all active interfaces. This strategy may cause overhead in the network, consuming unnecessary bandwidth. The benefits and disadvantages of performing blind duplication will be analysed, considering factors such as energy efficient, bandwidth consumption, and QoE metrics.
- Selective duplication, where packets are transmitted through the primary interface until a certain radio KPI meets a specific condition (e.g., Reference Signal Received Power, Reference Signal Received Quality or Signal-to-Interference-plus-Noise Ratio below a specified threshold for a specified time).

A basic scheme of the *mpconn* tool is depicted in Figure 8. As it is illustrated in Figure 9, the MAGW will be deployed in the LL by placing by placing it atop the trailer responsible for animal transportation. The main stakeholder for the Danish LL (DTL A/S) has granted approval for installing the box in one of their trucks. The specific routes for truck measurements are yet to be determined. Nevertheless, the stakeholder has indicated willingness to conduct multiple measurements along the same route and make slight route modifications to assess areas with known poor coverage.

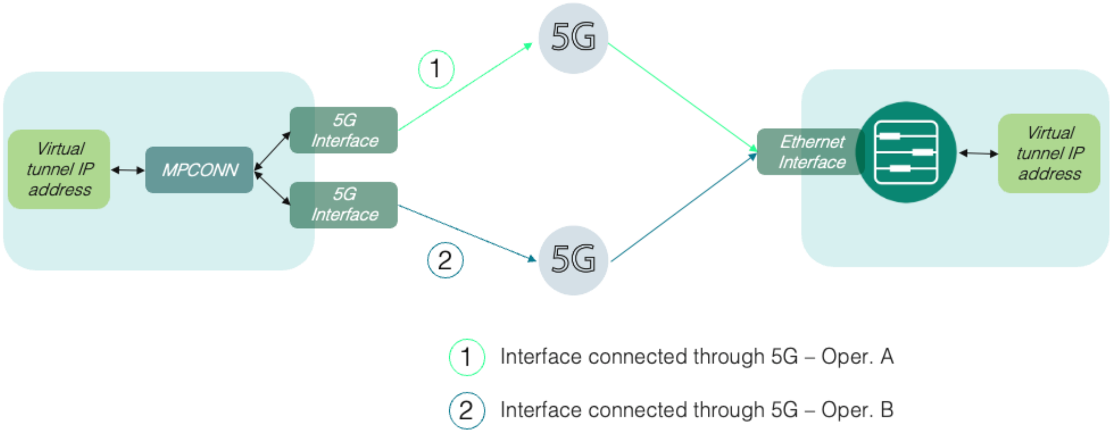

Figure 8. Basic scheme of mpconn tunnelling program.

Figure 9. Truck where MAGW will be mounting for experimental tests.

Specifics regarding the tests, such as packet size, target bandwidth, or sampling interval, etc., are based on the use case requirements and can be found in deliverable D1.2 [2].

Technical Requirements

Three key technical requirements have been identified for this use case. The first one requirement emphasizes the provision of a 16-kbps uplink throughput for non-continuous telemetry transmission, encompassing location data, trailer onboard sensor information, and onboard sensors for the truck to enhance safety and operational efficiency. The second requirement focuses on enhancing online navigation systems for route optimization, necessitating a specified downlink throughput ranging between 8 and 14 Mbps, as outlined in deliverable D1.2. To ensure the availability of these data rates, the third technical requirement, R3.3, mandates a service reliability of 99.9% for this use case.

To obtain numerical values on achievable data rates and service reliability we will perform two different mobility campaigns (MC):

- *MC4 – Single-operator multi-connectivity*

We will evaluate the benefits of using this multi-connectivity mode with various metrics. Firstly, we will assess cellular coverage along the route (MC4.1). Since the requirements of this use case are primarily throughput-related, throughput will be measured. Due to the nature of this use case, latency may not be considered relevant, although it is deemed important for potential future use cases. Hence, latency will also be measured in this test to account for future scenarios where different data types might be transmitted to the fleet manager centre. To establish a baseline for comparing the multi-connectivity solution (MC4.3), we will initially evaluate the current latency and throughput experienced by the trucks on the road (MC4.2).

- *MC5 – Multi-operator multi-connectivity*
  In this scenario, we will investigate the advantages of having two active links with different operators through similar tests as described above. Coverage tests will be repeated (MC5.1) in case routes differ. Even if routes remain the same, coverage data will be collected to validate the results from MC4.1. Latency and throughput tests will again be conducted for single-connectivity (MC5.2) and multi-connectivity (MC5.3).

Table 7 outlines a summary of the tests that will be performed and the tools that will be used to obtain the results. As depicted in the table, throughput values will be obtain using *IPerf3,* while Round-Trip Time (RTT) latency will be obtained using the *Ping* Linux tool.

Table 7. Summary of tests to be performed for UC3.1.

Test ID	Test Description	Tools/service	Metrics
MC4.1	Coverage Tests	Cellular Modems Logger	RSRP, SNR [dBm, dB]
MC4.2	Single connectivity	Ping	Latency measurements [s]
		IPerf3 (UDP)	Throughput measurements [bps]
MC4.3	Multi-connectivity	Ping	Latency measurements [s]
		IPerf3 (UDP)	Throughput measurements [bps]
MC5.1	Coverage Tests	Cellular Modems Logger	RSRP, SNR [dBm, dB]
MC5.2	Single connectivity	Ping	Latency measurements [s]
		IPerf3 (UDP)	Throughput measurements [bps]
MC5.3	Multi-connectivity	Ping	Latency measurements [s]
		IPerf3 (UDP)	Throughput measurements [bps]

Table 8 outlines a tentative timeline for the various tests to be conducted. As indicated, the experimental tests are set to commence earliest at M21. In the meantime, emulation work and tests within AAU's lab facilities are being performed to assess optimal packet duplication strategies, as explained in deliverable D5.1 [6]. Those tests will be carried out from M17 to M21. It is important to note that adjustments to the timeline may occur based on the progress of emulation tests, the truck's availability, the feasibility of desired routes, or other influencing factors.

Table 8. Time plan for validation of connectivity solutions for UC3.1.

Month	Description
M18	Meeting with DTL A/S to clarify the practicalities: when could the truck be available, how to set up the MAGW on the truck (power, placement, etc.), and others.
M21 – M23	Getting setup ready and testing of equipment onboard.
M24 – M25	MC4.1 & MC4.2 – Single-connectivity tests (measurement and processing)
M25 – M26	MC4.1 & MC4.3 – Single-operator multi-connectivity tests (measurement and processing)
M26 – M27	MC5.1 & MC5.2 – Single-connectivity tests (measurement and processing – potentially different routes)
M27 – M28	MC5.1 & MC5.3 – Single-operator multi-connectivity tests (measurement and processing)

3.3.2 UC 3.2 – License Plate Recognition

This use case targets the automation of the license plate recognition when the transportation truck arrives at the location for (un-)loading the piglets. These locations could be situated along the transportation route for resting the piglets until they reach the final destination or the farms where the piglets are (un-)loaded. As an enabler for the automation process the video surveillance camera that controls the road barrier should be installed on the approaching road towards the facility as presented in Figure 10. Consequently, the video camera should have sufficient uplink throughput (depending on the used encoder) to bring the image of the license plate to the remote license plate recognition software that is also connected to the authorisation databases. As a result, if the truck with the license plate has all the necessary authorisations, the road barrier can be lifted, and the transportation truck could reach the facility.

Deployment Strategy

The planned set-up for the field test is depicted in Figure 11 where a farm was selected in the Brabant province in The Netherlands. The uplink throughput for a video link communication will be tested via the following connectivity components:

a) Local 5G network (pending on the local n77 band 3.3 GHz to 4.2 GHz frequency license) that is created with Amarisoft's Callbox Classic [14] up to 50 MHz, as explained in detail in deliverable D2.1 [7].
b) Local Wi-Fi network provided by TP-Link's Archer AXE75 Wi-Fi router [15], capable of the WiFi6E that can utilize the 2.4 GHz and 5GHz, in addition to the new Wi-Fi 6GHz band.
c) A video camera (e.g. GoPro Hero product or simply a smartphone's video camera), emulating the connection to the road barrier.
d) For the end-to-end test of the video link, the plan is to use the local connectivity at the farm for the backhauling. If feasible, with the support of SES's satellite terminal connected to our 5G local network, tests with a satellite backhauling link will also be conducted.

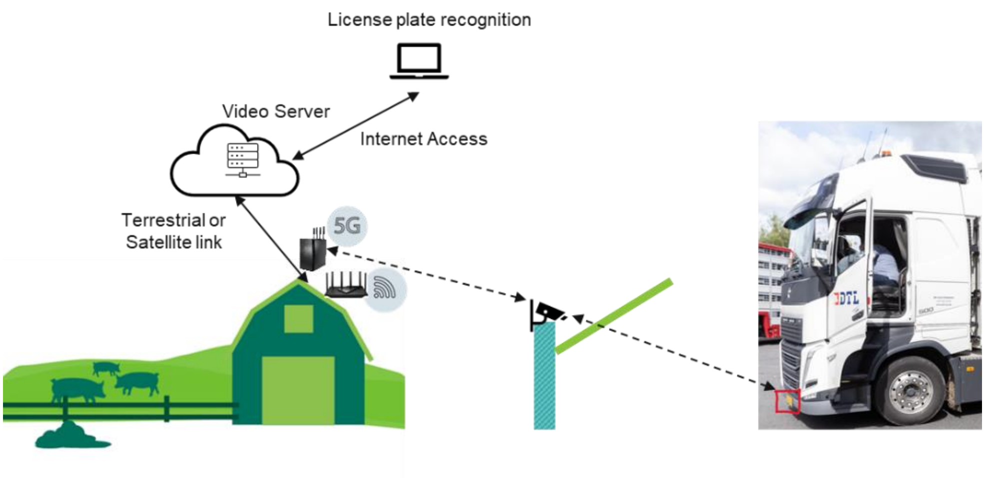

Figure 10. Automated license plate recognition and barrier control: schematic view of the envisioned technical set-up.

Figure 11. Automated license plate recognition and barrier control: selected farm location in Brabant province (The Netherlands).

Tests and Validation

The following performance tests are envisaged (see also Table 9):

1) Performance evaluation of local 5G and Wi-Fi: uplink throughput versus distance
   a. The approach would be to measure the achievable uplink throughput via 5G or Wi-Fi between the wireless terminal and the local access point. This performance measurement will be done via *IPerf* installed locally and then measuring from different locations around the farm.
   b. The measurement data will produce a graphical representation illustrating the UL throughput in Mbps relative to the distance in meters between the measurement location and the wireless access point. This graphical representation will be used to determine in which areas around the farm facility the uplink KPI of 10 Mbps, see deliverable D1.2 [2], can be achieved. This is a valuable insight for dimensioning and optimizing wireless communication in the farm environment.
2) Performance evaluation of the communication link including a transport backhauling link to internet
   a. The approach would be to measure the achievable UL and DL throughput (and round-trip delay) between the video server and the video camera, including the backhaul transport link between the farm and the internet. Depending on the available budget and availability of a satellite link terminal, a backhaul transport

link could be also realized with a satellite connection. This performance measurement will be done via IPerf installed on a server within the internet domain.

  b. Expected outcome is a defined area around the farm location where the required uplink throughput of 10 Mbps and a round-trip delay below 1s, see deliverable D1.2 [2], can be achieved.

3) End-to-end performance evaluation of the communication solution
  a. Depending on budget availability and cooperation with COMMECT partners for end-application deployment, an end-to-end mock-up of the automated license plate recognition can be tested, including the analysis of the video image, and using a road-barrier control algorithm.

Table 9. Time plan for validation of connectivity solutions for UC3.2.

Month	Description
M15 (Dec. 2023)	Farm site visit and inspection of the facility for the connectivity set-up
M16 - M18 (Jan - Mar 2024)	Connectivity set-up testing and local 5G frequency license arrangement in band N77
M19 - M20 (Apr - May 2024)	5G and Wi-Fi uplink throughput performance versus distance (local wireless access)
M21 - M22 (Jun - Jul 2024)	Performance evaluation of the communication link including the transport backhaul link to internet
M24 - M25 (Sep - Oct 2024)	End-to-end performance of the communication solution for automated license plate recognition

Technical Requirements

The specific technical requirements targeted for this use case focus on the achievable UL throughput, particularly from the camera installed at the road barrier to the network, for video link communication. This throughput is contingent on the distance from the 5G or Wi-Fi wireless access point. To meet the demands of near real-time automatic license plate recognition, the estimated uplink throughput requirement is set at around 10 Mbps, as suggested in deliverable D1.2 [2]. Additionally, the end-to-end delay is stipulated to be less than 1 second to ensure swift and efficient processing of the recognition system.

3.3.3 UC 3.3 – Monitoring of Livestock Loading/Unloading Processes

This use cases targets the automation of the (un-)loading process when the transportation truck arrives at the desired location e.g. situated along the transportation route for resting the piglets until they reach the destination or the farms where the piglets are (un-)loaded. The schematic view of the connectivity solution for this use case is illustrated in Figure 12. The video camera (e.g. either installed on the trailer or at the location entrance) should have sufficient UL throughput (depending on the used encoder) to transport the live video feed to the remote location where either an expert or a computer vision software can process the video image. The analysis of the video feed is expected to give different insights for the (un-)loading process such as automated counting of the piglets, automated recognition of ill or injured piglets, etc.

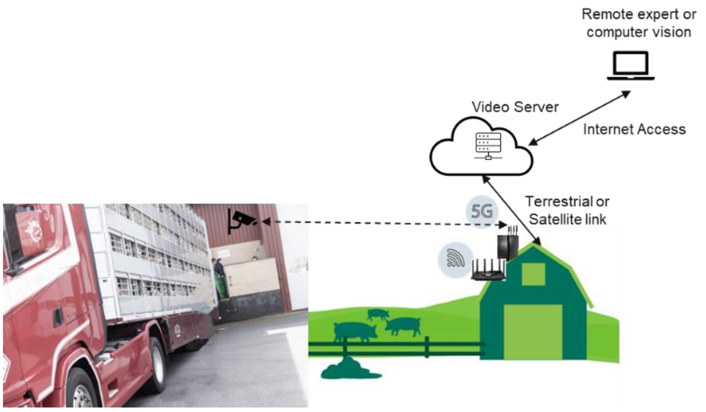

Figure 12. Schematic view for the (un-)loading set-up.

Deployment Strategy

The planned set-up for the field test is depicted on Figure 13 where a farm was selected in the Brabant province in The Netherlands. The uplink throughput for a video link communication will be tested in a similar way as for the UC3.2, i.e. either via a local 5G network created with Amarisoft's Callbox Classic or via a local Wi-Fi network provided by TP-Link's Archer AXE75 Wi-Fi router, capable of WiFi6E. A video camera, (e.g. GoPro Hero product) will be used for emulating the connection to the remote expert/computer algorithm. For the backhauling tests, next to the already available terrestrial connectivity at the farm, additionally a satellite link will be tested for the backhaul transport network.

Figure 13. Selected farm location with planned 5G and Wi-Fi installations and envisioned measurement route.

Tests and Validation

The same performance tests are envisaged for this use case as they are defined for UC3.2 (see also Table 9), namely:

1) Local 5G and Wi-Fi uplink throughput wireless access testing versus distance
2) Performance evaluation of the communication link including a transport backhauling link to internet
3) End-to-end performance evaluation of the communication solution
    a. Depending on budget availability and cooperation with COMMECT partners for end-application deployment, an end-to-end mock-up of the automated (un-)loading of the livestock can be tested, including the analysis of the video image and feedback of the analysis results.

Technical Requirements

Similar to use case UC3.2, the targeted technical requirements for this use case (UC3.3) are the achievable uplink throughput from the video camera towards the network depending on the distance from the 5G or Wi-Fi wireless access point and the end-to-end delay. As the livestock (un-)loading process video monitoring should work almost in real-time the required uplink throughput is estimated to be around 10 Mbps and the end-to-end delay should be less than 1 s.

3.4. LL N.4 – Türkiye – Smart Olive Tree Farming

Türkiye is one of the most essential olive-producing countries in the world. Olive production in Türkiye is done using traditional methods, and most producers consist of communities living in rural areas. Improving harvest quality and reducing the cost per kilogram of olives are the most critical challenges in Turkish olive agriculture and farming activities. Türkiye lags developed countries in integrating technology into olive agriculture.

LL Türkiye will focus on the olive tree orchard and explore how soil and other conditions in olive cultivation can be closely monitored using the connectivity solutions of the 3rd Generation Partnership Project (3GPP), enabling disease-insect risk management and optimal spraying decisions. Narrow Band-IoT (NB-IoT) and enhanced Machine Type Communication (eMTC) will be implemented in LL Türkiye to provide digital solutions to farmers. Data collected from sensors installed in the field will feed early warning systems that notify end users of the most effective control period against diseases and pests. The use of early warning systems will support environmental sustainability. The yield and quality of the product can be increased with correct, timely and sufficient olive cultivation techniques. Two use cases have been identified for LL in Türkiye.

The technical requirements defined in D1.2 [2] aim to ensure that quality and performance targets are met in the Türkiye LL. These technical requirements include accessibility, power consumption, integrity, and coverage.

3.4.1 UC 4.1 – Microclimate Monitoring for Early Disease and Pest Recognition

Monitoring micro-climatic conditions is crucial, particularly in the management of ring spot disease (*Spilocaea oleaginea (Castagne) S. Hughes*), a potential threat to olive crops. Leveraging data obtained from weather station sensors and employing models that consider pathogen-environment interactions, it becomes possible to forecast and issue early warnings for disease onset under specific conditions. This use case aims at providing an automated Information and Communication Technology (ICT) system generating alerts. Regular monitoring of climate data and the developmental stages of the disease-causing pathogen is essential. The *Spilocaea oleaginea fungus* can be spread locally through rainwater, insects, and wind. In instances where chemical control is required, optimal spraying times are determined, and relevant announcements are made. The implementation of early warning systems not only enhances the sustainability of olive cultivation but also contributes to increased yield and improved quality of harvested olives.

Weather station data will provide information for modelling the olive fly's establishment. Olive fly population development is dependent on microclimate events. Insights provided by weather station devices will establish the correlation between pest population and microclimate occurrences.

To enhance coverage in the rural areas of Turkish olive orchards, this use case requires the integration of IoT, cellular XG, and other wireless networks. This integration will facilitate the seamless transfer of data from soil-plant-atmosphere sensor stations. These stations are equipped to collect essential information such as soil water content, soil and air temperature, precipitation, and other pertinent parameters, as illustrated in Figure 14.

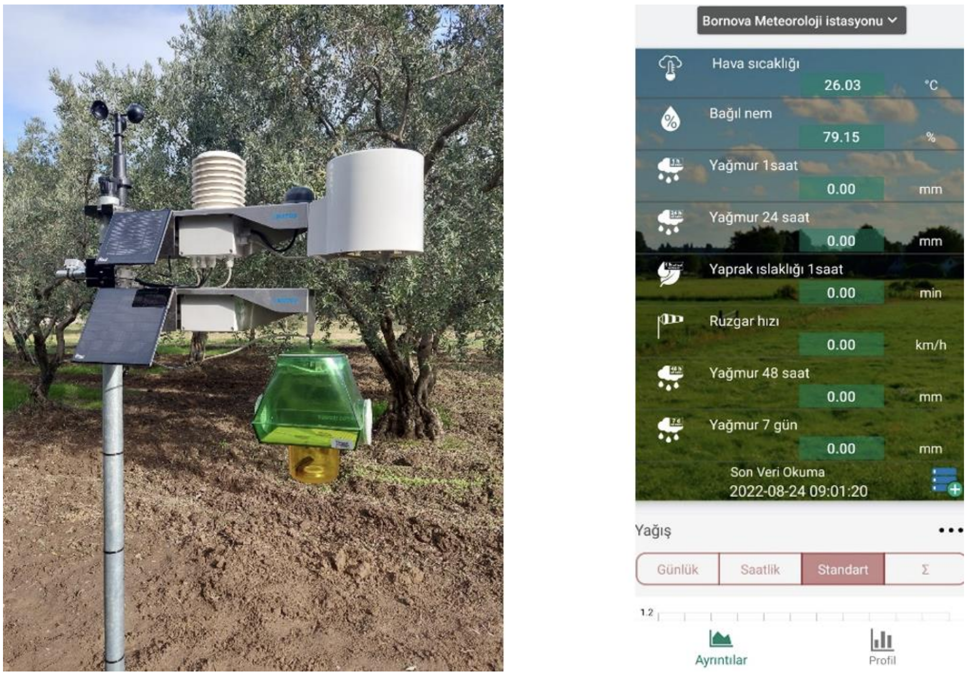

Figure 14. Soil-plant-atmosphere sensor station, including soil sensors and weather data acquisition sensors.

Deployment Strategy

In the Türkiye LL, the deployment of the first use case for microclimate monitoring and early disease and pest detection is planned in two different olive production locations. These locations are in Izmir and Antalya, as pointed out in Figure 15. The selection of these cities was made considering production quantities and climatic conditions.

Figure 15. Locations of UC4.1 deployments in the Turkish Living Lab.

In the Izmir and Antalya campuses, where the installation is completed, the deployed equipment includes two climate stations, two delta traps and cameras, two yellow sticky traps and cameras, two manual traps without cameras, two tractor tracking devices, and one phenology tracking camera. The deployment process involved resolving calibration and connection issues. An example of digital traps and weather stations deployed in the LL is shown in Figure 14.

Positioning the devices away from other external factors (buildings, trees) that may skew the measurements is essential. In the Türkiye LL, climate stations were optimally positioned to accurately represent the garden conditions while minimizing the impact of external factors.

The data received from weather stations will play a key role in implementing an early warning system against key diseases and offers additional insights into the life cycle of pests. Critical processes such as flowering and harvest time may be monitored remotely with phenology cameras, allowing to make remote decisions when transportation to the area is impractical due to unfavourable land conditions.

The use of tractor tracking devices provides valuable information about the vehicle's involvement in traffic processes, work intensity, and operational procedures throughout a production season. This data allows for the evaluation of equipment efficiency and the assessment of whether additional equipment is required.

Tests and Validation

To address the challenging coverage zones in Türkiye’s LL, the preferred radio access technologies for transmitting sensor data are NB-IoT and eMTC. The validation and testing of these deployments cover a set of technical requirements aimed at assessing the performance of radio access networks in the natural environment.

All devices used in Türkiye LL are battery-powered with solar panels except the trackers that are used for the tractors. The time plan for validation of this use case is shown in Table 10. Network energy saving tests for the installed equipment will be planned in May and September 2024.

Table 10. Time plan for the deployments of UC 4.1.

Month	Description
M1 – M3 (October 2022)	Field survey 1 (İzmir) 2 (Antalya)
M4 – M6 (January 2023)	Installation of weather stations (2 Locations)
M8 – M18 (April 2023)	Field survey for Installation of XG weather stations and sensors
M19 – M24 (May 2024)	Network energy saving tests for the installed equipment.
M25 – M36 (September 2024)	Second iteration of the network energy saving tests for the installed equipment by data driven optimisation techniques.

Technical Requirements

The requirements for this use case were defined in deliverable D1.2 [2] and include random access success rate, power consumption decrease, network availability, and warning accuracy. They are calculated after deploying devices and radio access networks successfully. The data collected from the sensor and radio access networks are analysed at the application, user, and cell levels. The LL Türkiye will evaluate the technical requirements during the deployment in the olive tree orchards. The preliminary stage of the deployment plan is ready and completed, but the results of the field test will be compiled and presented in deliverable D5.4 [5].

3.4.2 UC 4.2 – Monitoring of Pest Insect Traps

The endemic challenge of olive fly (*Bactrocera oleae*) in olive cultivation requires constant monitoring and control due to its rapid reproduction and potential for extensive damage. Traditional agriculture employs manual food and pheromone traps for monitoring [16]. Still, these require periodic physical inspections, which are challenging in Türkiye's often mountainous olive-growing regions.

UC4.2 introduces a digital solution to this issue, particularly addressing user needs for effective pest control. This involves the deployment of advanced connected electronic pest traps designed explicitly for capturing olive flies. These traps, integrating yellow sticky surfaces with pheromones, are further enhanced with electronic components, including digital cameras and wireless transmission capabilities, facilitating remote monitoring via smartphone or web applications. This system significantly reduces the need for frequent manual inspections, allowing for timely and efficient pest control interventions.

The efficacy of these digital traps lies in their lightweight design and autonomous functionality, including integrated cameras, modems, and solar-powered sources. They are poised to revolutionize pest monitoring in rural areas, enabling centralized agricultural advisory centres to guide orchard owners and managers in pest control strategies remotely. The spatial distribution of these traps is strategically planned according to orchard size and pest targets.

This initiative also encompasses a broader scope, considering the feasibility of such digital trapping systems for global applications in pest population monitoring. These traps promise timely pest control by ensuring stable data transmission and leveraging artificial intelligence for pest identification, thereby mitigating potential yield and quality losses in olive production.

Moreover, this approach aligns with broader agricultural objectives, such as enhancing broadband connectivity in rural areas through XG-based or IoT wireless networks and addressing energy efficiency challenges. The placement of digital traps and transmission units is strategically determined to ensure comprehensive orchard coverage and reliable data transmission.

In summary, UC 4.2 not only offers an innovative solution to olive fly control but also represents a significant step in integrating technology into traditional agriculture, potentially increasing yield, improving quality, and thus augmenting the income of rural olive farmers.

Deployment Strategy

In implementing the second use case under the LL Türkiye, the determination of deployment sites was guided by the regional olive production volumes and climatic conditions. As shown in Figure 16, three distinct areas were identified for this purpose: Izmir, Antalya, and Hatay. However, the unexpected earthquake in early 2023, significantly impacting Hatay, necessitated a re-evaluation of deployment plans. After comprehensive field inspections and collaborative deliberations among the LL partners and stakeholders, the installation of the digital traps for olive fly monitoring was successfully executed on January 3, 2024, in the Mersin province.

The deployment equipment in this use case includes mostly digital traps, a crucial tool in combating olive fly infestations. These traps were selected for their potential to offer remote connectivity and diagnostic capabilities, aiming to resolve challenges in effective olive fly management.

Optimal positioning of digital traps within the olive grove is critical for efficacy. It is essential to mitigate conditions conducive to olive fly proliferation and to ensure that trap placement accurately represents the overall field conditions. In the Türkiye LL context, digital traps have been strategically positioned to reflect the specific environmental factors of the groves, avoiding external influences.

Deploying work trackers and early warning systems necessitates carefully considering energy consumption, coverage, and connectivity. The smart olive tree farming devices in Türkiye are compatible with a range of network technologies, including NB-IoT and eMTC, alongside former XG technologies such as 2G and 3G. These transmitters are versatile in utilizing any XG technology for data transmission, underscoring the project's commitment to technological adaptability and efficiency.

Figure 16. Locations of UC4.2 deployments in the Turkish Living Lab.

Figure 17. Color, pheromone and bait trap (Delta).

Tests and Validation

To address the challenging coverage zones in Türkiye's LL, the preferred radio access technologies for transmitting sensor data are NB-IoT and eMTC. The validation and testing of these deployments cover a set of technical requirements aimed at assessing the performance of radio access networks in the natural environment. Network energy saving tests for the installed equipment will be planned in May and September 2024.

Table 11. Time plan for the deployments of UC 4.2.

Month	Description
M1 – M3 (October 2022)	Field survey 1 (İzmir), 2 (Antalya), and 3 (Hatay-Mersin).
M4 – M17 (January 2023)	Installation of weather stations (3 Locations).
M8 – M18 (April 2023)	Field survey for Installation of XG weather stations and sensors.
M19 - M36 (May 2024)	Network energy saving tests for the installed equipment.
M19 - M36 (September 2024)	Second iteration of the network energy saving tests for the installed equipment by data driven optimisation techniques.

Technical Requirements

The requirements for use case UC4.2 were defined in D1.2 [2], including fly detection accuracy, uplink throughput, and decreased power consumption. The preliminary stage of the deployment plan is ready and completed, but the final results of the field test will be compiled and presented in deliverable D5.4 [5]. The uplink throughput measures the time it takes for the sensor to send the data to the network. This background operation occurs frequently and has little impact on overall system performance.

3.5. LL N.5 – Serbia – Sustainable Agriculture and Preservation of Natural Environment

Agriculture plays a crucial role in Serbia's economy and employment landscape. However, current farming practices rely heavily on traditional methods, resulting in sub-optimal approaches with limited consideration for environmental impact. In response to these challenges, the LL in Serbia aims to revolutionize agricultural production by implementing more efficient practices, such as reducing pesticide usage and employing optimal irrigation techniques powered by renewable energy. This transformation will be facilitated through the introduction of digital services.

The LL is set to be implemented in the Vojvodina province, specifically in the agricultural fields of Gospodjinci village, situated amidst the Mrtva Tisa and Jegrička nature parks. LL Serbia plans to harness the potential of mobile solar generators, edge technology, and various renewable energy sources to establish a community-driven Low Power Wide Area Network (LPWAN).

Through the integration of real-time data from environmental measurements (including air temperature, humidity, air quality, precipitation, and noise levels), soil parameters (such as temperature, moisture, and conductivity), and crop-related factors (including growth status and vitality), LL Serbia aims to develop decision-making algorithms. These algorithms will then generate automated recommendations for farmers, guiding them on the necessary measures to enhance their agricultural practices. Considering this objective, five different use cases were identified for the Serbian LL.

3.5.1 UC 5.1 – Creation of a Shared Rural Infrastructure

Establishing a robust LPWAN network infrastructure with high availability and reliability is necessary to enable data collection and transmission. The data acquired from the devices deployed in the field are forwarded to the agroNET platform (see architecture in D2.1 [7]), enabling centralized storage, analysis, and access to the information. For this purpose, mobile solar generators, designed in the form of foldable tractor trailers with the capability to generate up to 30 kW of electricity, will play a key role in the Serbian LL. These generators will serve multiple functions, including: 1) powering a LoRaWAN gateway to ensure connectivity for the deployed sensors, 2) providing energy to irrigation pumps, replacing fuel-run pumps and promoting sustainability, 3) powering one or more video cameras to monitor the status of the crops, enhancing precision agriculture practices and 4) powering an edge Machine Learning (ML) device responsible for processing video and audio streams, along with sensor data, enabling on-site data analysis and decision-making.

Deployment Strategy

We adopted a two-phase approach for the deployment of a LoRaWAN network at Mrtva Tisa, the LL location. In the first phase, deployed during M12, we established a LL office within a container, which contains all the devices intended for deployment during the full LL implementation. This includes solar panels with batteries of large capacity, a LoRaWAN gateway, Bluetooth Low Energy (BLE) network, Wi-Fi network, an edgeML gateway, four video cameras, and a set of LoRaWAN sensors (location tracker, air quality, presence, door opening/closing). Additionally, a router with a 4G backhaul connection is included. This setup allows validating the configuration and run the initial network tests in the live environment while having all the necessary tools and convenience of an office setting rather than being outdoors.

During this phase, we are investigating the incorporation of networking and computing equipment into solar trailers to determine the most convenient locations for additional devices, identify mounts to be constructed, and plan the packaging and mounting procedures once the equipment is deployed in the field.

The second phase involves the full deployment, wherein two solar trailers will be equipped with COMMECT equipment (4G router, LoRaWAN gateway, BLE network, edgeML gateway, 2 video cameras, a weather station, and a set of soil moisture and temperature sensors). Beyond the mobile installations, devices for monitoring water quality, noise levels and air quality will be deployed at fixed locations. These devices will be powered by their own solar panels or connected to the solar panel at the LL office.

Table 12. Time plan for the deployments of UC 5.1.

Month	Description
M12 (August 2023)	Phase 1: installation of Living Lab
M15 (November 2023)	Initial network coverage tests
M18 (February 2024)	Equipping solar trailers with COMMECT equipment, deploying environmental sensors
M19 (March 2024)	Phase 2: Moving solar trailers to the living lab location, start gathering data, run the second iteration of network coverage and network capacity tests
M20 – M26 (April – Oct 2024)	Using equipment and validating environmental, agriculture and community platforms.

Tests and Validation

To validate deployment in terms of coverage and throughput, a set of LoRaWAN sensors were transported around the designated area while continuously transmitting data. Among these devices, one was equipped with a built-in GPS sensor to enable location tracking. The transmitted data was collected by a LoRaWAN gateway, specifically, the Long Range -G-868-E/4G model, deployed at the LL office location. This gateway was connected to a 4G router for Internet access. The installation height of the gateway was approximately 4 meters, and it utilized a long-range antenna with a gain of 2.5 dBi (vertical polarization, omni-directional). The sensors employed for this validation process include:

- SenseCAP T1000 [17] – A compact GPS tracker that utilizes GNSS/Wi-Fi/Bluetooth for precise indoor and outdoor location tracking. Data is transmitted every 5 minutes or on request when a button is pressed.

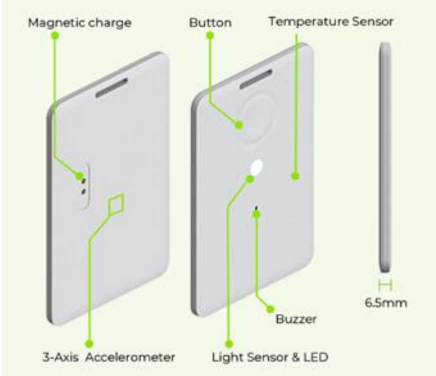

Figure 18. SenseCAP T1000 sensor.

- Milesight AM319 [18] – A comprehensive Indoor Air Quality (IAQ) sensor for detecting CO2 concentration, temperature, humidity, light, HCHO/O3 level, barometric pressure, PM2.5, PM10 and motion, with Tx Power 16 dBm (868 MHz) and Sensitivity -137 dBm @300bps. Data is transmitted every 10 minutes if in range.

Figure 19. Milesight AM319 sensor.

- Milesight WS301 [19] – A magnetic contact switch with Tx Power 16 dBm (868 MHz) and Sensitivity -137 dBm @300bps. Data is transmitted on each change open/closed.

Figure 20. Milesight WS301 sensor.

During data transmission tests, the sensors were transported either by walking or riding a bike around the gateway location. The planned routes followed a circular pattern or formed a sine function, depending on the surrounding area and terrain accessibility. The route, covered over several days of testing, is presented in Figure 21 as the orange path. The LoRaWAN gateway's position is denoted by an "x" along the riverbank. The terrain in the general vicinity is predominantly flat, with no significant obstructions aside from the trees. The area left to the gateway is higher than the location of the gateway.

Figure 21. LoRaWAN gateway location and covered route.

Technical Requirements

Following successful deployment and data collection during the validation period M19 to M26, validation of the requirements specified in deliverable D1.2 [2] will be performed:

- Maximal power output capability: the power capability of mobile solar generators should constantly deliver up to 30kW of electricity. This requirement will be verified by measuring power consumption of the connected equipment during validation period.
- Stable power supply: batteries capacity to power-up the connected devices must be provided for at least 12 hours.
- Mobility and roadworthiness: the electric power generator must be mobile and roadworthy. Following the validation period efficiency of the power generator must be at 95%.
- Server uptime: LoRaWAN server must ensure high availability and reliability with a target goal of 99% uptime.
- Device connectivity: the 100% connectivity rate for all deployed devices will be evaluated by measuring the collected and analyzed data during the validation period. This is achieved by properly positioning LoRaWAN gateway while coverage and throughput test are performed to enable adequate device installation.
- A standard, enterprise-grade platform: the tests will be created at a later stage.
- Battery lifetime: the battery lifetime should exceed 2 years.

Preliminary Results

The initial set of tests were carried out during M15. The results obtained from several days of testing indicate that the coverage in the rural area (agriculture fields) is estimated to be approximately 3 km. In contrast, the coverage in the urban area (village) is approximately 1 km. It should be noted that the altitude of the gateway location is slightly lower than that of the village, and the terrain behind the village is also elevated. The signal propagation in the urban area is obstructed by buildings and other obstacles, while in rural areas, the forest near the riverbank poses a limiting factor. The tests will be repeated in the second phase with the antenna positioned at a higher location. These adjustments will help optimizing signal propagation and improving the overall performance of the LoRaWAN network.

The throughput, as measured by spreading factors, is visually represented in Figure 22. Spreading factor 7 (depicted in blue) indicates areas with the highest throughput, primarily observed in the rural surroundings. The test also utilized spreading factors 8 (red), 9 (purple), 10 (yellow), 11 (green), and 12 (black), with lower throughput, particularly noticeable in the urban area. The prevalence of spreading factor 7 is evident across the tested region, especially in the rural areas. Spreading factors 8 and 9 dominate the bordering areas adjacent to the agricultural fields. In contrast, urban areas exhibit a dominance of spreading factors 9, 10, and 11, reflecting the network's adaptation to different spreading factors based on the specific characteristics of each environment.

Figure 22. Spreading factor for covered area of testing.

3.5.2 UC 5.2 – Securing Crops and Equipment

Detection of field activities, securing assets and monitoring crops growth by video monitoring and edge ML computing algorithms is the main objective of UC 5.2. As described in D4.1 [4], solar trailers will be equipped with video cameras and edge ML computing devices. The role of the edge ML devices is to process video streams captured by installed video cameras to detect specific security related events (detecting people, vehicles, equipment on site) and observations related to agriculture (e.g., status of the crops – size, colour).

Deployment Strategy

As already described for UC5.1, preliminary tests related to energy efficiency using ML algorithms on edge ML devices for processing farming images is presented in D5.1. Deployment of equipment used in this use case (solar panels, batteries, edgeML gateway, video cameras) is described in UC 5.1. The initial testing of the setup, from the perspective of energy consumption was done in the test lab environment. During M18, the tests will be repeated in the living lab office, while the final tests will be done once mobile trailers with the COMMECT equipment is deployed in the field (see Table 12).

In addition to the energy consumption related tests, a set of tests to evaluate performance of the ML algorithms as well as the ability to execute in real time will be run.

Technical Requirements

Following successful deployment and data collection during the validation period M19 to M26, validation of the requirements specified in D1.2 will be performed:

- Real-time video processing: two streams from video cameras should be processed in real time.
- Edge ML remote configuration: edge devices must be remotely configured.

3.5.3 UC 5.3 – Shared Environment Monitoring Platform

Environmental monitoring of air and water quality with noise levels in the nature park covered by LL Serbia is contributing to its preservation. Collected and analysed measurements are stored centrally at agroNET platform and are made available to all interested parties.

Tests and Validation

The deployment used for this use case is the same as the presented for UC5.1 and can be found in Section 3.5.1. For the shared environment monitoring platform, the ability to regularly collect data from all deployed devices is one of the key success criteria. To achieve that, the devices must be deployed in the network coverage area and the capacity of the network must be sufficient to support concurrent transmissions from all deployed devices. While the LL will not have an extensive number of sensors, it can be envisaged that in case of adoption and full-scale deployments, the number of deployed devices will grow. To that end, the tests will be focused on the evaluating the capacity of the network, and the impact of having several LoRaWAN gateways deployed in the area. To emulate larger number of devices, the frequency of transmissions from all deployed devices will be increased from the default frequency (as required by the application) to higher levels.

The default numbers of transmissions per deployed environment monitoring device are air quality (more than 20 measurements per day per site), water quality (more than 4 measurements per day per site) and noise levels (more than 20 measurements per day per site).

Technical Requirements

Following successful deployment and data collection during the validation period M19 to M26, validation of the requirements specified in D1.2 [2] will be performed by counting the number of received measurements during the day:

- Network capacity (air quality): more than 20 measurements per day per site should be received at agroNET platform.
- Network capacity (water quality): more than 4 measurements per day per site should be received at agroNET platform.
- Network capacity (noise level): more than 20 measurements per day per site should be received at agroNET platform.
- Network capacity (notifications): more than 10000 push notifications within 15 minutes should be sent, that can be tracked in the execution logs.

3.5.4 UC 5.4 – Shared Digital Agriculture Platform

Data received from the installed monitoring devices and soil conditions are stored and analysed centrally by agroNET platform, that will provide decision support on irrigation, disease predictions and measurements to be taken based on the input from environmental parameters.

Tests and Validation

The deployment used for this use case is the same as the presented for UC5.1 and can be found in Section 3.5.1. As described in the previous use case, the capacity of the LoRaWAN network will be one of the key success factors for full-scale COMMECT-like deployments. It is envisaged that in a such case, the number of agriculture related sensors (weather stations, soil moisture and temperature sensors, etc.) will be significantly higher than the number of environmental sensors. To that end, the network capacity calculations are even more important, considering the number of default messages per monitored field (at least 24 transmissions per day).

Technical Requirements

Following successful deployment and data collection during the validation period M19 to M26, validation of the requirements specified in D1.2 will be performed by counting the number of received measurements during the day:

- Network capacity (environment): more than 20 measurements per day per site should be received at agroNET platform.
- Network capacity (soil): more than 4 measurements per day per site should be received at agroNET platform.
- Network capacity (notifications): more than 10000 push notifications within 15 minutes should be sent, that can be tracked in the execution logs.

3.5.5 UC 5.5 – Shared Rural Community Platform

The shared rural community platform will be used as a central point for exchanging data, best practices, and advice in the farming community. It will collect relevant market data, information about the best agriculture practices related to selected crops, notifications of interest to the community (e.g., disease prediction models, irrigation recommendations, etc.). All collected information will be made available via the COMMECT DST.

Deployment Strategy

The shared rural community platform will be deployed in M19 to serve as a communication hub for the rural region. It will be deployed in cloud with web and mobile interfaces.

Tests and Validation

The tests will be created at a later date. The focus of testing will be on usability, the richness and accuracy of the content.

Technical Requirements

Following successful deployment and data collection during the validation period M19 to M26, validation of the requirements specified in D1.2 [2] will be performed:

- Expandability: system must be flexible and expandable with the addition of new features.
- Multilanguage support: easy implementation of user interface in different languages must be supported.
- Access to platform: platform should be accessible at list through web browsers, mobile application, and messaging application.
- Accuracy of responses: system must incorporate local data to ensure response accuracy with target value of more than 90%.

4. Conclusions

This document is the first version of the *Report on Technical Validation in the Living Labs.* It provides an overview of the current status of task T5.2 within the COMMECT project, specifically focusing on the validation of the COMMECT connectivity solutions within the Living Labs. The document describes the deployment strategy and validation plans for each LL, aligning with the use cases identified in deliverable D1.1 [1]. A tentative time plan is presented for each LL, establishing a structured pathway for the thorough evaluation and validation of the connectivity solutions developed in WP2.

While the connectivity solutions and validation plans are tailored to specific use cases, it should be noted that the solutions proposed in one LL for a particular use case can be applied to other use cases in different LLs. This cross-applicability is particularly noticeable in the use of IoT sensors within the agro-forestry industry. Specifically, four LLs (Luxembourg, Norway, Türkiye, and Serbia) have identified use cases where IoT sensors can significantly enhance the management and productivity of agro-forestry businesses.

Video uploading is also part of different use cases identified across the LLs and is considered relevant to these industries but currently lacks an optimal connectivity solution, especially in rural and remote areas. The connectivity solutions proposed to address this issue could be cross-evaluated and will be compared in the last version of this deliverable. Likewise, the solutions proposed for the Danish LL, intended for livestock transport industry, could potentially benefit the entire transport sector.

These solutions are also applicable to other pilot projects with similar needs. This emphasizes their versatility and potential impact beyond the initial LLs context, proving their value for further digitalization of the rural communities.

This deliverable contains preliminary results for some use cases. Comprehensive results will be incorporated into deliverable D5.4 [5] – *version 2* of this document, where a one-to-one comparison will be conducted between the targeted technical requirements (outlined in deliverable D1.2 [2]) and the actual values achieved through the implementation of the connectivity solutions in each LL. This subsequent deliverable will provide an assessment of the project's technical outcomes against pre-defined benchmarks.

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