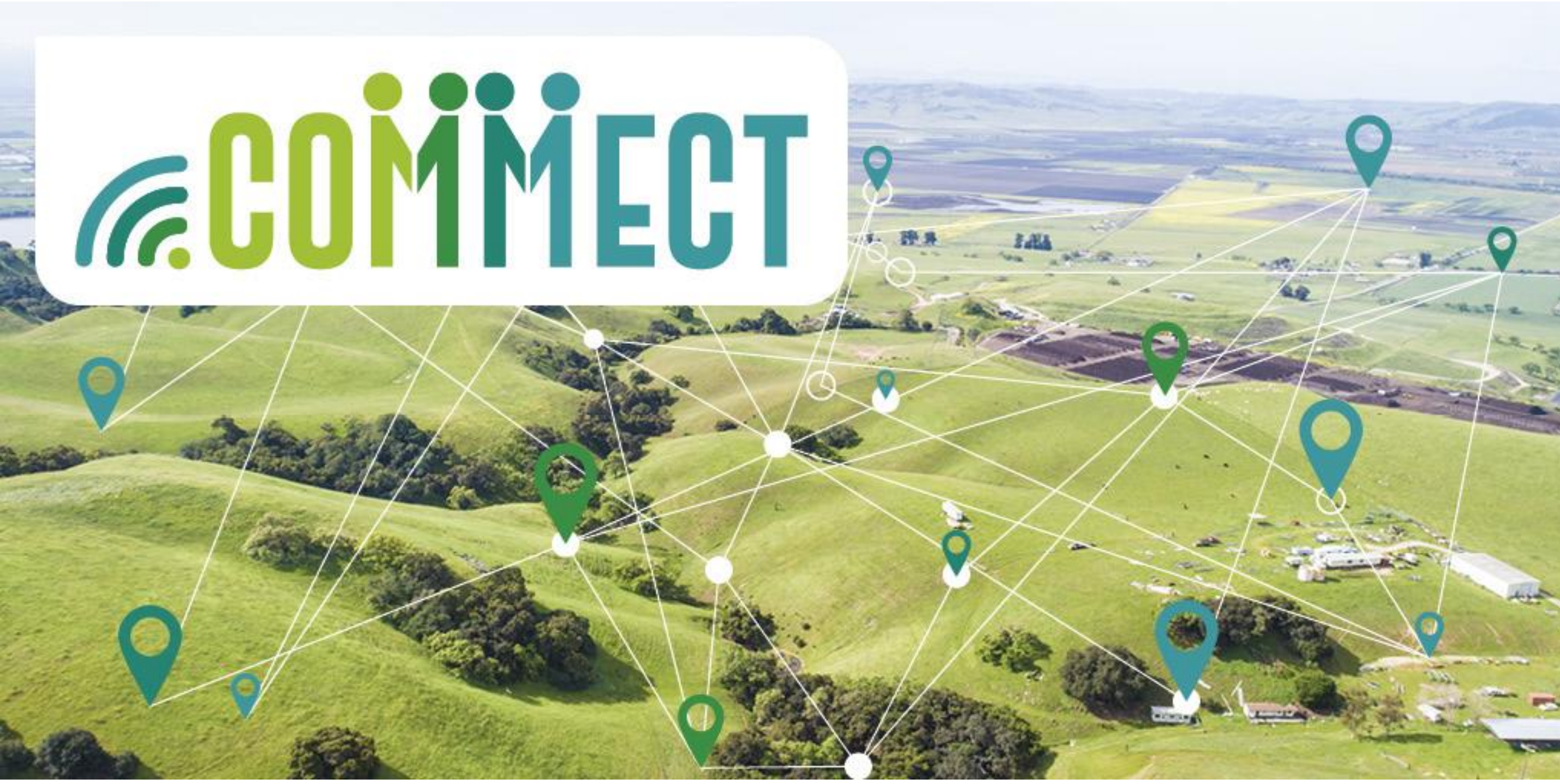
Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions



Deliverable 2.1
5G Connectivity Platforms – Version 1

May 2023

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

5G Connectivity Platforms

WP2 - XG, Edge and Last-Mile Energy Efficient Solutions for coverage extension

Deliverable ID	**D2.1**
Deliverable Name	**5G Connectivity Platforms**
Lead Partner	SES
Contributors	AAU, DNET, LIST TCELL, TNO, TNOR

PUBLIC

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 digital divide and addressing the need of rural communities with cost-effective and environmental-friendly connectivity solutions.

In this framework, this document describes the output of the COMMECT *Task 2.1 – 5G Connectivity Platforms*. It is the first version while more information will be provided in the second version. This deliverable describes all the connectivity platforms which will be used in the COMMECT to allow the onboarding and validation of wide range of use cases in function of end-user needs.

These connectivity platforms leverage the existing state of the art 5G platforms, developed in previous H2020 projects, and extend the coverage by deployment of new RAN sites. Particularly, the connectivity platforms which are described in this deliverable include facilities in Luxembourg, Norway, the Netherlands, Denmark, Turkiye and Serbia which offer wide range of terrestrial and non-terrestrial technologies.

Finally, this document is used as a basis for the definition of the COMMECT architecture in the *Task 1.3 – COMMECT Architecture Definition* of the Work Package 1 (WP1) as well as in the implementation and testing of the Living Labs in Work Package 4 (WP4) and Work Package 5 (WP5), respectively.

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Abbreviations

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5GC	5G Core
5GSP	5G Service Platform
AAU	Active Antenna Unit
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AMR	Autonomous Mobile Robot
AP	Access Point
APN	Access Point Name
AR	Augmented Reality
AUSF	Authentication Server Function
AWS	Amazon Web Service
AP	Access Point
B5G	Beyond 5G
BBU	Baseband Unit
BS	Base Station
BSS	Broadcasting Satellite Service
CA	Carrier Aggregation
Cat4	Category 4
CDMA	Code-Division Multiple Access
CE	Conformité Européenne
CMOS	Complementary Metal-Oxide Semiconductor
CNF	Cloud-native Network Function
CO	Carbon Monoxide
CO2	Carbon Dioxide
CPU	Central Processing Unit
CRD	Custom Resource Definition
DAS	Distributed Antenna System
DL	Downlink
DN	Data Network
DNR	Digital Noise Reduction
DSB	Double Sideband
E2E	End-To-End

EC	Electrical Connectivity
ED	End Devices
eDRX	Extended Discontinuous Reception
eMBB	enhanced Mobile Broadband
eMTC	Enhanced Machine Type Communications
FCC	Federation Communication Commission
FDD	Frequency Division Duplex
FSS	Fixed Satellite Service
FTE	Full Time Equivalent
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GSM	Global System for Mobile communications
GW	Gateway
HDMI	High-Definition Multimedia Interface
HSS	Home Subscriber Server
HTS	High Throughput Satellite
HW	Hardware
K8s	Kubernetes
I2C	Inter-Integrated Circuit
ICR	Infrared Cut-filter Removal
IGW	Intelligent Gateway
IoT	Internet of Things
IP	Internet Protocol
IPS	Intrusion Prevention System
IWLAN	Industrial Wireless Local Area Networks
LAN	Local Area Network
LED	Light-Emitting Diode
LEO	Low Earth Orbit
LNS	LoRaWAN Network Server
LPWAN	Low-Power Wide Area Network
LTE	Long Term Evolution
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LTWTA	Linearized Travelling Wave Tube Amplifier
M2M	Machine to Machine
MAC	Medium Access Control

MAGW	Multi-Access Gateway
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMTC	Massive Machine Type of Communications
MNO	Mobile Network Operator
MOCN	Multi Operator Core Network
MPSL	Multi-Protocol Service Layer
NAS	Non-Access Stratum
NB-IoT	Narrowband-Internet of Things
NCOM	Nokia Cloud Operations Manager
NF	Network Function
NFV	Network Function Virtualization
NFVO	Network Function Virtualisation Orchestrator
NGP	Next Generation Platform
NO	Nitrogen Monoxide
NO2	Nitrogen Dioxide
NPN	Non-Public Network
NR	New Radio
NR ARFCN	New Radio Absolute Radio Frequency Channel Number
NRF	Network Repository Function
NMS	Network Management System
NOC	Network Operation Center
NOrC	Nokia's Orchestration Center
NOW	Network on Wheels
NSA	Non-Standalone
NSSF	Network Slice selection Function
NSaaS	Network Slice as a Service
NTN	Non-Terrestrial Network
NUC	Next Unit of Computing
NVDLA	NVIDIA Deep Learning Accelerators
O3	Ozone
OCI	Orange Cloud infrastructure
OSP	Open-Source Platform
OTA	Over-The-Air
PC	Personal Computer
PGW	Packet data network Gateway

PLMN	Public Land Mobile Network
PM	Particulate Matter
PoE	Power of Ethernet
PoP	Point of Presence
PPDR	Public Protection Disaster Relief
PSM	Power Save Mode
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RFID	Radio Frequency Identification
RMS	Remote Management System
RoHS	Restriction of Hazardous Substances
RS	Remote Sensing
Rx	Receiver
SA	Standalone
SATA	Serial Advanced Technology Attachment
SDN	Software Defined Network
SGW	Serving Gateway
SIM	Subscriber Identity Module
SMF	Session Management Function
SMS	Short Message Service
SNO	Satellite Network Operator
SPI	Serial Peripheral Interface
SSD	Solid State Drive
SSPA	Solid-State Power Amplifier
SW	Software
TDD	Time Division Duplex
TOPS	Tera Operations Per Second
TT&C	Telemetry Tracking and Control
TWTA	Travelling Wave Tube Amplifier
Tx	Transmitter
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink

UMTS	Universal Mobile Telecommunications Service
UPF	User Plane Function
USB	Universal Serial Bus
UT	User Terminal
VIM	Virtual Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Function
VoLTE	Voice over LTE
VPD	Vapour Pressure Deficit
VPN	Virtual Private Network
VR	Virtual Reality
VSAT	Very Small Aperture Terminal
WCDMA	Wideband Code Division Multiple Access
WDR	Wide Dynamic Range
WLAN	Wireless Local Area Network
WP	Work Package
XDP	eXpress Data Path

1. Introduction

In this first chapter, the deliverable's objective, structure, and the relation with COMMECT project are briefly presented and discussed.

1.1. Objective of the Document

One of the main objectives of the COMMECT project is to design innovative, cost-effective, and energy-efficient (5G, last mile, and edge) connectivity solutions that can increase the attractiveness of the rural remote area to businesses and individuals.

In this framework, this deliverable aims to describe the connectivity platforms which will be used in the COMMECT project to allow the on-boarding and validation of wide range of use cases in function of the end-users needs. These connectivity platforms leverage the existing state of the art 5G platforms developed in past H2020 projects and extend the coverage by deployment of new Radio Access Network (RAN) sites.

Particularly, i) the Luxembourg Facility of SES in Betzdorf (Luxembourg) which focuses on satellite backhauling solutions, ii) the Norway Facility, a state of the art, truly multi-vendor 5G facility which supports 5G Standalone (SA), iii) the 5Groningen facility of TNO (Netherlands), iv) the 5G Smart Production Lab of AAU (Denmark), v) the IoT XG test Platform of TCELL (Türkiye) and vi) the IoT Connectivity Platform of DNET (Serbia) are described.

1.2. Structure of the Document

The deliverable follows the structure briefly described below:

- Section 2 focuses on the description of the Luxembourg Facility which mainly provides satellite backhaul solutions, for multi-connectivity RAN.
- Section 3 focuses on the description of the Norway Facility which is split into three parts: i) Next Generation Platform (5G-VINNI NEXT), ii) Network on Wheels and iii) 5G Private Network.
- Section 4 focuses on the description of the 5Groningen Facility of TNO which has two field implementations, an indoor 5G network at a Warehouse facility and a 4G/5G lab facility.
- Section 5 focuses on the description of the Smart Production 5G Lab of AAU, where the lab is equipped with network deployments from different technologies such as Industrial Wireless Local Area Networks (IWLAN), Wi-Fi 6, MuLTEfire, and different configurations of Long-Term Evolution (LTE) and 5G.
- Section 6 focuses on the description of the IoT XG test Platform of TCELL which hosts samples of network components of all generations.
- Section 7 focuses on the description of the Connectivity Platform of DNET which utilizes mobile solar generators, edge technology, and renewable energy sources to establish community based on Low-Power Wide Area Network (LPWAN) network that covers extended rural areas.
- Section 8 describes the interconnection between the Luxembourg Facility and the 5Groningen Facility, in the context of the Living Lab Denmark.

1.3. Relation to Other Work Packages in COMMECT

The *Task 2.1 – 5G Connectivity Platforms* will be used as a basis in other Work Packages (WP), and their related tasks are:

- T1.3 on COMMECT Architecture Definition.
- T4.1 on Living Lab Luxembourg Digitalization of Viticulture.

- T4.2 on Living Lab Norway Connected Forestry.
- T4.3 on Living Lab Denmark Connected Livestock Transport.
- T4.4 on Living Lab Türkiye Smart Olive Tree Farming,
- T4.5 on Living Lab Sustainable Agriculture and Preservation of Natural Environment,
- T5.2 on Technical Validation in the Living Labs.

Therefore, the Task T2.1 will help in the definition of the COMMECT architecture (WP1) and its results will be implemented in the Living Labs (WP4) and tested in lab and/or real conditions (WP5).

2. Connectivity Platform: Luxembourg Facility

This section provides the description of network services for the Luxembourg Facility which is owned and operated by SES in collaboration with LIST and mainly provides satellite backhaul capabilities. The key features of the Luxembourg Facility are elaborated hereinafter.

2.1. RAN

- The Luxembourg Facility includes different prototype RAN equipments:
- Long Range Wide Area Network (LoRaWAN) Internet of Things (IoT) technology and Long Range (LoRa) devices to support massive Machine Type of Communications (mMTC) for smart and precision farming applications.
- Smart IoT Gateway (GW) (prototype device developed by SES) which can gather and process data from the different IoT devices.
- AMARI Callbox Classic (more details are provided in Section 2.1.3).

2.1.1. LoRaWAN Network Architecture

In the last decade, a large variety of IoT communication technologies has gradually emerged, reflecting a large diversity of application domains and communication requirements. Among them, LPWAN technology came out as a better choice for enabling long-range connections, at greater cost and power efficiencies. LPWANs allow low power devices interacting directly with some gateways through long-range transmissions. Therefore, they are suitable for smart agriculture and precision farming applications that require low data-rate, and are tolerant to packet loss, and transmission delay. Many LPWAN technologies have been developed over the last years, including LoRa, Sigfox, and Narrow Band IoT (NB-IoT) among many others. LoRa and LoRaWANs offer the possibility for *private networks deployments* (without the need of a Telecom Operator), and easy integration with existing platforms (for example, The Things Network).

Figure 1 illustrates the LoRaWAN network architecture which has a star topology. Several End Devices (EDs, equipped with different sensors) can only communicate through wireless LoRa links with any of the gateways in their transmission range. Multiple gateways are connected to a central LoRaWAN Network Server (LNS), which is responsible of managing the entire network. The gateways are only responsible for forwarding the messages from end devices toward the network server, encapsulating them in UDP/IP (User Datagram Protocol/Internet Protocol) packets. The network server is also responsible for sending acknowledgment packets and configuration messages (for example, Medium Access Control (MAC) commands) to the end devices. The LNS can be interconnected with several application servers, which enable different applications and services.

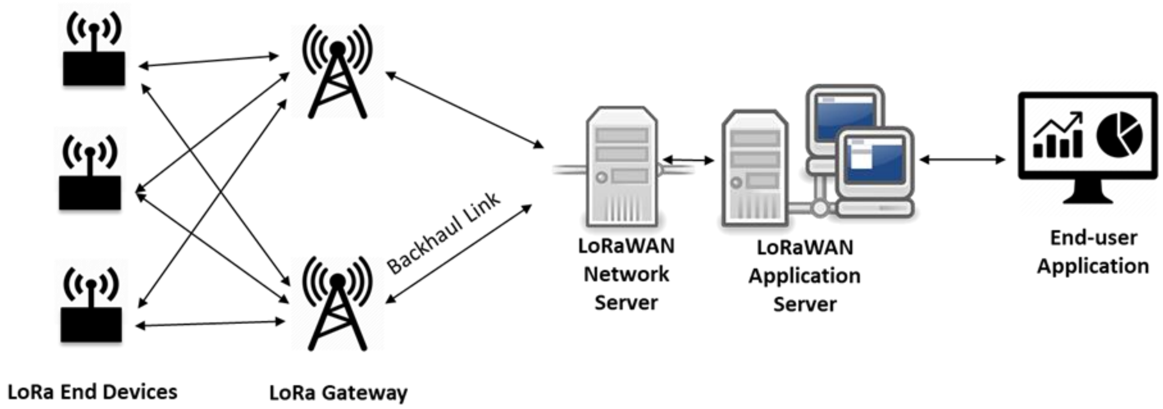

Figure 1: LoRaWAN Network Architecture

LoRa IoT devices

Across its laboratory and field infrastructure, the ERIN department at LIST offers a wide range of standardised and customised services in the fields of testing, measurement, analysis, and methods. ERIN hosts LoRaWAN-based IoT testbed facilities, including several prototyping end devices (such as NUCLEO-L476RG, etc.) and Raspberry-Pi based Gateways (for example, RAK Wireless 7244C). They are programmed to optimise SW/HW resources, meeting the needs of different applications. ED are equipped with multiple sensors (soil moisture, temperature, humidity, etc.) according to the application requirements. Several networks have been deployed in agriculture fields in Luxembourg, using off the shelf and multi-vendors devices (Lumbara, Libelium, etc.). Energy constraints and use of renewable energies have been investigated during the in-field deployment. Besides low-power IoT devices generating small data, LIST IoT lab also works with advanced IoT devices (for example, camera enabled with edge capabilities) generating big data (high-resolution pictures) and connected over the 5G network provided by POST Luxembourg.

Figure 2: 5G camera and LoRa Devices (Soil-Moisture Sensors and Weather station)

2.1.2. Smart IoT Gateway

The Smart IoT GW is the system element responsible for the appropriate routing and sorting of sensor data, coming from one or more sensor networks to higher layer data consolidation services and Machine to Machine (M2M) platforms. For performing these operations, the Smart IoT GW is able to interconnect multiple physical interfaces, as well as extracting and transforming messages as data traverses from one side to the other.

The Smart IoT GW exposes several physical and data-link interfaces to receive sensor data. Sensors can send messages to the Smart IoT GW either wirelessly (with technologies such as IEEE 802.11 or LoRa), or directly connected to the device (via Ethernet, Inter-Integrated Circuit (I2C), or Serial peripheral Interface (SPI)). The Smart IoT GW is smart enough to manage the routing and direct the received messages to the right output interface in the right timing, more specifically, it intelligently routes the data to satellite or terrestrial backend networks. Several factors have been taken in consideration in this operation:

- Context such as the current geographical location of the Smart IoT GW or its situation relative to potential recipients of messages.
- Message prioritization due to urgent messages that need to be forwarded immediately over other messages that can be grouped together for channel usage optimization.
- Channel availabilities like in cases where constrained communications impose a specific interface linked to a channel, such as a satellite link in situations where the Smart IoT GW is deployed on a ship sailing far away from the coast. In a diametrically opposed scenario, the ship would be moored in the port and the Smart IoT GW would

favour a link established by 4G LTE taking advantage of a nearby mobile network station.

The Smart IoT GW is illustrated in Figure 3. The Smart IoT GW is based on a Raspberry Pi 4 protected by a universal and modular metal case. Furthermore, to allow the installation of the PG1301 LoRaWAN connector as a "shield" module on top of the Raspberry Pi, an extension frame has been added to the metal case. For persistent storage, a 120GB Solid State Drive (SSD) is attached to the Raspberry Pi's Universal Serial Bus (USB) port using a Serial Advanced Technology Attachment (SATA)-to-USB3.0 adapter. The Antenna of the LoRaWAN connector shield has been moved to the side of the RE-Computer Case using an extension cable, which could be plugged though a dedicated hole in the base frame.

In summary, the Smart IoT GW ensures the connectivity for a vast number of heterogeneous IoT devices, by harmonizing different IoT technologies and application protocols and formatting data to be transferred across the network, terrestrial either satellite. Therefore, the IoT interoperability enables the federation of different IoT platforms within heterogeneous domains, overcoming the compatibility issues between both standard and non-standard, proprietary and custom M2M solutions. Furthermore, it enables a better exploitation of data in optimization and prediction, which provides the greatest business value.

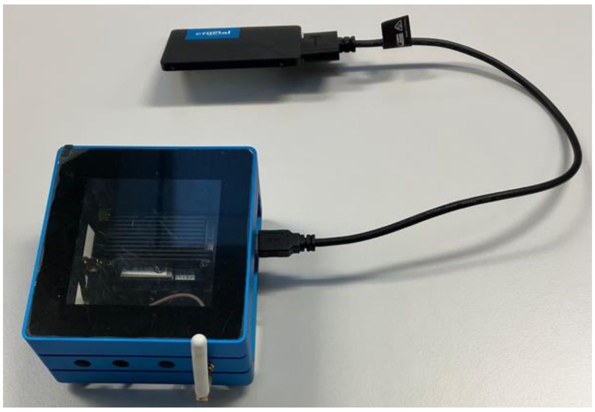

Figure 3: Smart IoT GW

2.1.3. AMARI Callbox Classic

The AMARI Callbox Classic (see Figure 4) provides 5G SA and Non-Standalone (NSA) RAN capabilities for enhanced Mobile Broadband (eMBB) use cases as well as 4G/LTE (Long Term Evolution) RAN capabilities for NB-IoT use cases. The AMARI Callbox Classic operates in the sub-6 GHz frequency range.

Figure 4: AMARI Callbox Classic

2.2. Edge Nodes

The Luxembourg Facility involves two Edge Nodes:

- A Fixed Edge Node, where the remote Very Small Aperture Terminal (VSAT) terminal is fixed/stationary (see Figure 5) located at the SES' teleport in Betzdorf, Luxembourg, which corresponds to a 1.2-m Ku-band VSAT terminal.

Figure 5: Fixed Edge Node installation at SES's Teleport in Betzdorf, Luxembourg: Out-Door Unit (ODU) + Indoor Unit (IDU)

- A Nomadic Edge Node, where the remote VSAT terminal corresponds to the SatCube Ku-band small-factor transportable terminal (see Figure 6). The SatCube Ku-band small-factor transportable terminal corresponds to a light weight, compact, portable satellite terminal that enables broadband connectivity almost anywhere on earth. It is a compact, user-friendly device that delivers quick connectivity empowering people at work to communicate and deliver critical services. The highly intuitive user interface makes its operation simple. SatCube's technology is specifically developed to tap High Throughput Satellites (HTS) to fulfil high-capacity communication needs, targeting industry verticals and workplaces requiring broadband connectivity where limited or no cellular connectivity is available. The Satcube Ku terminal includes a specially designed battery pack providing 3-hr transmit time; additional batteries are available and are hot-swappable, allowing continuous operation. In the Luxembourg Facility, the SatCube Ku terminal includes an embedded iDirect iQ200 modem, Wi-Fi LAN (Local Area Network), flat antenna, amplifier (high efficiency GaN Solid-State Power Amplifier (SSPA)), positioning system, upconverter, downconverter, heat pipe cooling system, and all necessary user interfaces such as graphical interfaces; all-in-one compact terminal, weighing just 8 kg and the size of a large laptop.

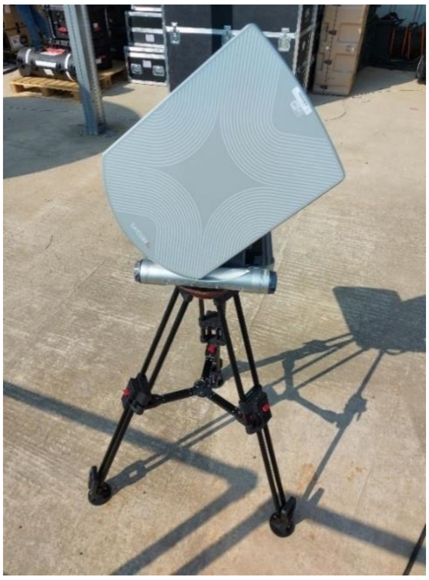

Figure 6: SatCube transportable satellite terminal

2.3. Transport and Core Network

The Luxembourg Facility mainly provides satellite backhaul capabilities. As such, the transport network between the RAN and Core Network corresponds to a satellite transport network. In particular, the space segment builds upon the SES ASTRA 2F satellite Geostationary Earth Orbit (GEO) satellite operated at the orbital location 28.2°East (for more details see Table 1 and Figure 7).

Satellite	ASTRA 2F
Orbital Type	Geostationary
Orbital Location	28.2º East
Orbital Control	+/- 0.1º relative to nominal OL
Satellite Type	EADS Astrium, Eurostar E3000 platform, 3-axis stabilized
Launch Vehicle	Ariane 5 ECA
Launch Date	28 September 2012
Design Lifetime	15 years
Payload Transponders	64 Ku-Band (TWTA and LTWTA, FSS: 26 and 36 MHz, BSS: 33 MHz) and 3 Ka-Band (LTWTA, 480 and 580 MHz)
Coverage Beams	Ku-Band: PE [Europe] (see Figure 7), UK [United Kingdom], WA [West Africa] Ka-Band: KaBB [France], steerable over the visible Earth
Further info:	https://www.ses.com/our-coverage/satellites/344

Table 1: SES's ASTRA 2F Space Segment

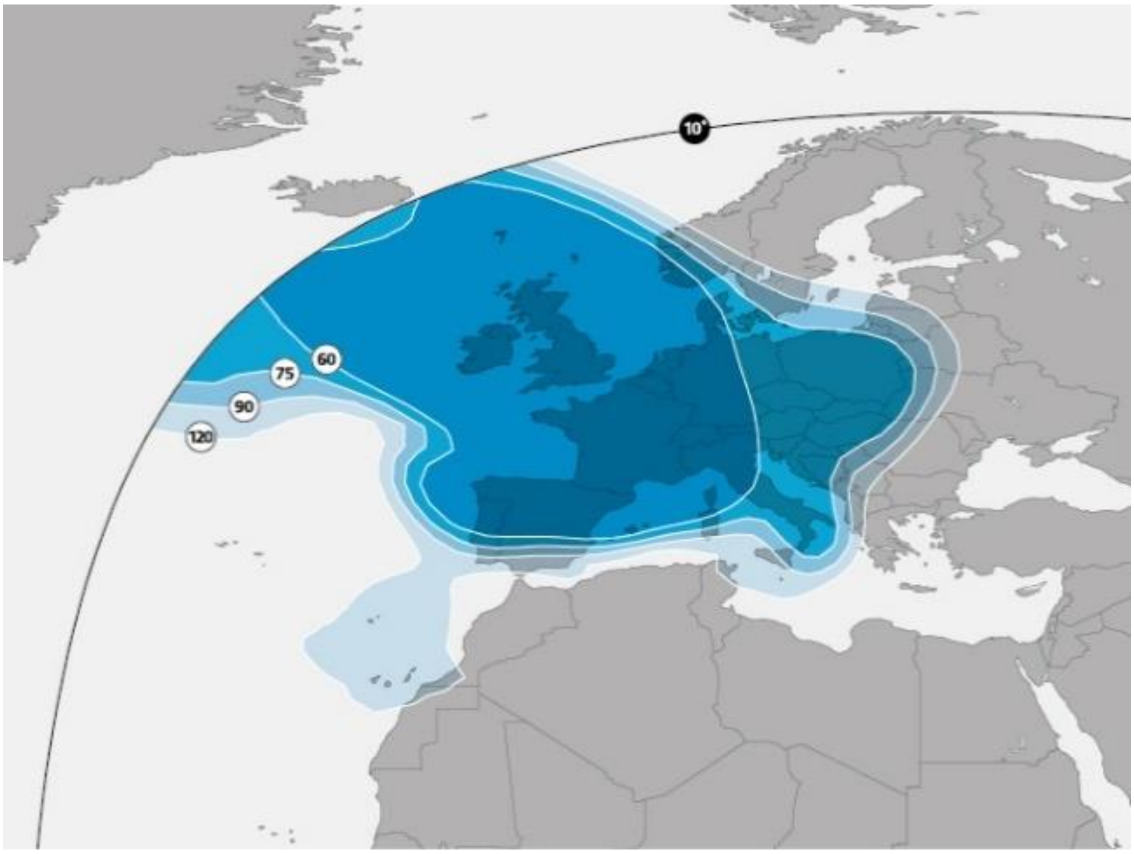

Figure 7: SES GEO Satellite ASTRA 2F (28.2ºE) - Europe Ku-band beam

The Radio Frequency (RF) uplink ground station corresponds to a 9m Ku band antenna (see Figure 8), while the RF downlink ground station corresponds to a 4.5m Ku band, multi-beam antenna (see Figure 9), both located at SES's teleport in Betzdorf, Luxembourg.

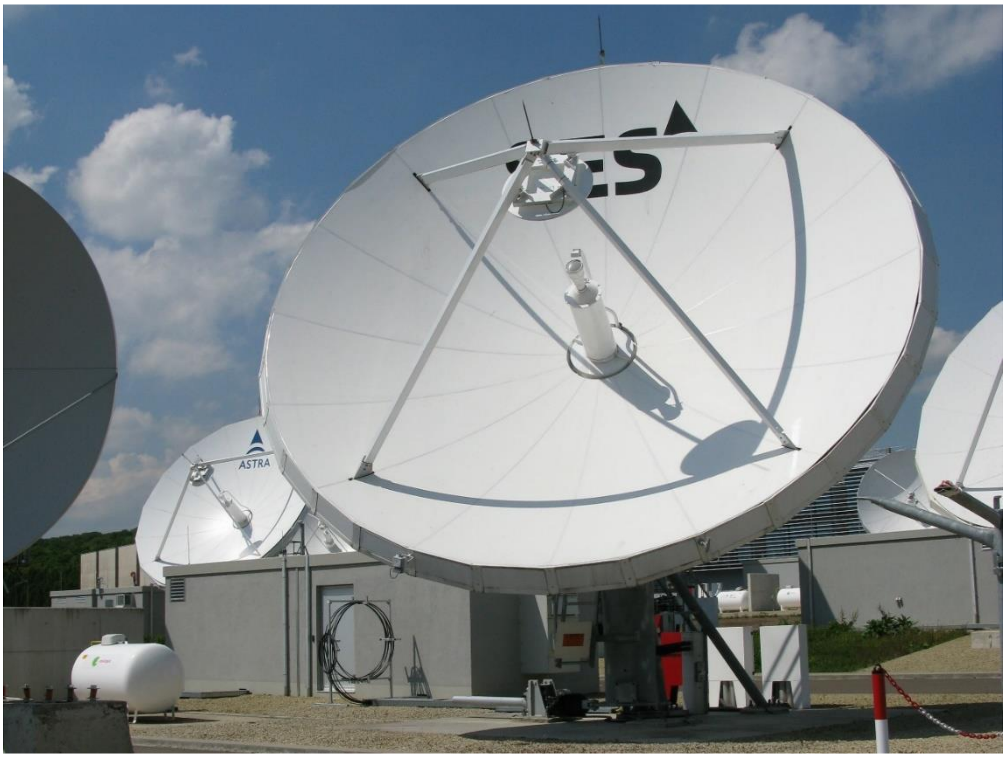

Figure 8: RF Uplink ground Station: ATF #33 Antenna, Diameter: 9m, Vertex, Tx/Rx, Ku-band

Figure 9: RF Downlink Ground Station: MBA#102 Antenna, Diameter: 4.5m, Multi-Beam Antenna, Rx only, Ku-band

Furthermore, the main teleport of SES is located in Betzdorf, Luxembourg, whose associated uplink/downlink facilities and hosting services are particularly relevant for this project. Main characteristics of the Betzdorf teleport are summarized as follows:

- State-of-art, highly reliable teleport.
- Seat of SES Headquarter as well (~ 400 Full Time Equivalents (FTEs) present).
- Access to 11 Orbital Slots.
- 35 antennas for uplink and Telemetry Tracking and Control (TT&C).
- On-net on SES Multi-Protocol Service Layer (MPSL) network.
- Terrestrially fully redundant with P&T Luxembourg and Colt as main providers.
- Meet-Me point at designated Point of Presence (PoP).
- 24/7/365 Network Operation Center (NOC) support in coordination with Washington teleport.
- From this location, SES “flies in the sky” more than 30 spacecrafts.

Finally, the baseline satellite ground segment corresponds to the ST Engineering iDirect's VelocityTM Intelligent Gateway (IGW) system (see Figure 11) residing at the SES' teleport site in Betzdorf, Luxembourg introducing a standard 3GPP Core Network (SatCore) to the satellite hub platform. Functions of the existing satellite network are offloaded, allowing SatCore to operate and manage network like a standard terrestrial 3GPP network. The existing satellite network is modified to comply standard RAN, referred to as Satellite RAN (SatRAN), node to the SatCore. In addition, the remote satellite terminal is modified to present itself as a standard User Equipment (UE) to the network, which allows it to connect to a SatCore in order to access network services.

The existing satellite network has been modified to comply with the standard 3GPP Release 15 compliant 5G Core Network architecture. That is, SatRAN has been modified and interfaces to SatCore have been aligned to the 5GC. As such, SatRAN presents itself as a standard 5G RAN whereas the remote satellite terminal presents itself as a standard 5G UE to the network. This enables for 3GPP services, such as authentication, billing, policy and charging control. This also enables the management of the satellite network slice by the Mobile Network Operator (MNO) in a seamless way, as if the MNO manages a standard 3GPP mobile network. As such, roaming between satellite and terrestrial mobile networks is enabled by such architecture. In fact, the SatCore may be operated by the MNO or the Satellite Network Operator (SNO), depending on the business model, and there may even be separate 3GPP core networks for the MNO and SNO networks. Initially, the existing non-3GPP based physical layer (for example, DVB-S2x/RCS2 based) is used over the satellite, which allows faster satellite integration into 5G. However, work is currently ongoing in 3GPP to investigate support for 5G New Radio (NR) air-interface over satellite. This would allow the SatRAN function to be fully 3GPP compliant.

Figure 10: SES Betzdorf Teleport

The satellite network functions are virtualised by transferring their execution environment from a dedicated server to a Virtual Machine (VM) using the OpenStack Pike Virtual Infrastructure Manager (VIM). Satellite Virtual Network Functions (VNFs) include the SatRAN software element, the satellite 3GPP Core Network function (SatCore), the satellite Network Management System (NMS) as well as additional auxiliary VNFs deployed on the same system using the OpenStack VIM.

Figure 11: Front and back of the iDirect's 5G-enabled Velocity™ Intelligent Gateway hub

2.4. Role of Luxembourg Facility in COMMECT

Vines are especially exposed to the effects of climate change and to the spread of diseases. Providing the winegrowers with near-real time information of their vineyards will offer them the possibilities to adapt their management according to their needs. The availability of this information allows them for a more time and cost-efficient planning. In the Luxembourg Living Lab the data will be processed by a Smart IoT GW offered by the Luxembourg Facility that supports several IoT communications technologies and protocols, and intelligently routes the data to satellite or terrestrial backend networks. Satellites can extend coverage in large agriculture fields and support the collection of massive IoT and RS data.

For this reason, the Luxembourg facility will also bring the satellite communications element into the COMMECT project. In particular, SES owned and operated GEO satellite in Ku band will be used. Furthermore, the Luxembourg Facility consists of a Software Defined Network/ Network Function Virtualization/Multi-access Edge Computing (SDN/NFV/MEC) enabled satellite 5G testbed which provides enablers for “plug and play” integration of satellite networks into 5G for the support of backhaul services and it will be used for advanced validation trials in the Luxembourg and Denmark Living Labs.

3. Connectivity Platform: Norway Facility

The Norway facility will support and provide the connectivity solutions for Norway living lab. Norwegian living lab mainly focuses on the forestry use cases. There are multiple use cases in consideration including remote control of forest machinery, Situational awareness in case of forest emergencies and use of drones in the forests. The facility will exploit the existing connectivity solutions and will extend these connectivity solutions based on final use case descriptions to provide cost-effective, and energy efficient solutions for forestry communities.

Currently, the Norway Facility is split into the following three parts as shown also in **Error! Reference source not found.**:

- Next Generation Platform (5G-VINNI NEXT).
- Network on Wheels.
- 5G Indoor Private Network.

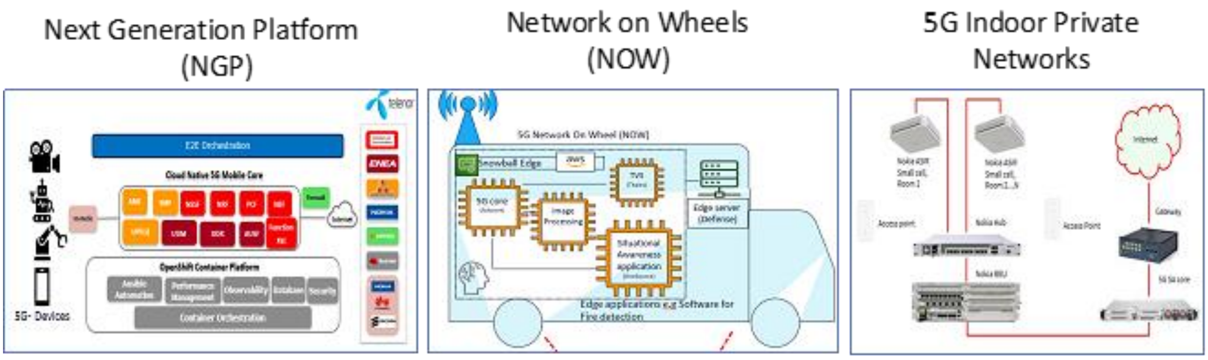

Figure 12 Norway Facility split into three parts.

More details are provided in the following sections.

3.1. Next Generation Platform (5G-VINNI NEXT[1]))

➲ The TNOR Next Generation Platform (NGP) is built to provide the 5G and Beyond 5G (B5G) services for i) vertical customers to experiment and validate their 5G-driven applications; ii) solution providers to integrate innovative solutions into the 5G platform and verify the functionality and performance in the end-to-end context; iii) telco operators to evaluate the deployment options of various 5G and B5G services and technologies, and identify the optimal solutions for the commercial 5G rollout. NGP or Public NGP is fully cloud-native and provides public 5G network services to all types of vertical customers (Figure 13 Architectural diagram of TNOR's Next Generation Platform

). It contains comprehensive value-added services to maximize the usage of the 5G services and optimize the customer experience, such as telco Edges, security services, testing and validation services, as well as full-fledged orchestration to enable the onboarding and deployment of multiple vertical services.

In general, the NGP is featured with:

- Cloud-native infrastructure, supported by Redhat Openshift. It is agnostic to the physical environment, which contains hardware from Nokia, Intel, and HPE.

[1] 5G VINNI Next or NGP is built upon Telenor's research and innovation previous 5G non-standalone facility, developed in Horizon 2020 5G VINNI project under grant agreement ID: 815279. The facility will be further extended to support several projects and their requirements.

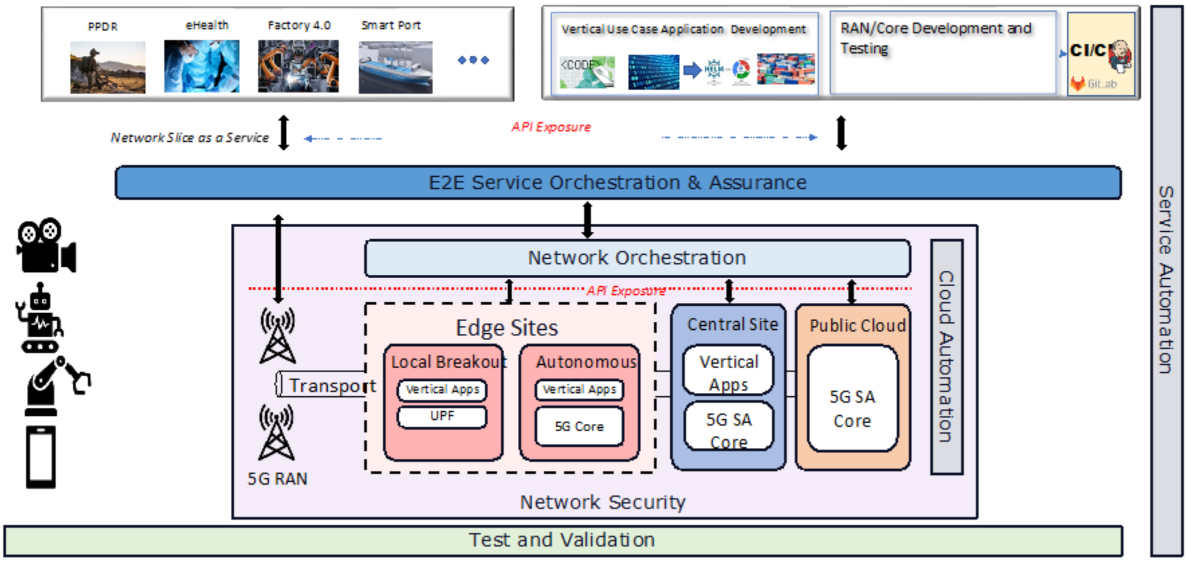

Figure 13 Architectural diagram of TNOR's Next Generation Platform

- Multi-vendor 5G SA core, supported by multiple vendors from Oracle, ENEA, and CASA systems. Each vendor provides a subset of SA 5G Core (5GC) Cloud-native Network Functions (CNFs) to provide End-to-End (E2E) network.
- Network slicing. Multiple 3GPP compliant 5G SA network slices are deployed, among which one slice is connected with real gNBs to provide the 5G services in Fornebu, Trondheim, and Svalbard. Another network slice is currently connected with emulated gNB and User Equipments (UEs) for the purpose of experimenting new features and functionalities, such as automation. More slices could be created on-demand and automatically, depending on the resource availability.
- Full-stack orchestration, supported by RedHat (infrastructure orchestration) and Nokia (network service orchestration). This orchestration system allows automating the deployment of infrastructure, network services, and network slices. In addition, vertical applications can also be deployed automatically through this orchestration system once they are prepared and packaged accordingly.
- E2E testing and validation, supported by Emblasoft and Keysight. External testing tools and a testing platform are in place to test and measure the performance of the infrastructure, the 5G components, and the E2E services [1]. There is also a plan to deploy an automated Testing-as-a-Service platform to automate the tests for multiple vertical customers simultaneously in the future.
- Professional security solutions, provided by Palo Alto. The NGP infrastructure is equipped with Palo Alto Firewall to secure the traffic in and out of the platform. In addition, a cloud-native application protection platform Prisma is also deployed to secure applications (including the 5G network services and vertical services) from code to cloud, as a way to accelerate the development and deployment of secure cloud-native applications.
- Customer-driven edge deployment, which can be classified into autonomous edge and local breakout edge. Depending on the customer's demand and resource availability, the edge site can be deployed and configured to be fully autonomous (such that the edge can be activated into a full 5G SA core when the connectivity to the central 5G

SA core is broken) or simply a local telco edge (so that local traffic can be processed locally to reduce the latency or the traffic load towards the central 5G SA core).

- Interconnection with public clouds that allows the deployment of 5G components in the public clouds. For example, an orchestration component from Nokia has been deployed in Amazon Web Service (AWS) and now it is also deployed in an Oracle Cloud Infrastructure (OCI).
- Interoperation with other platforms and/or facility sites which will facilitate the E2E service provisioning across multiple operators (or multiple domains/facility sites). Some vertical use cases consume 5G services spanning across multiple geographical regions, managed by different operators, for example, cross-country automotive services. The interoperations allow vertical customers to order 5G services from the NGP while the service is provisioned by another platform, or vice versa.
- Multi-site deployment (see Figure 14 NGP site deployment status
-). Currently, the NGP has deployed three RAN sites in Fornebu, Trondheim, and Svalbard as part of the public network.

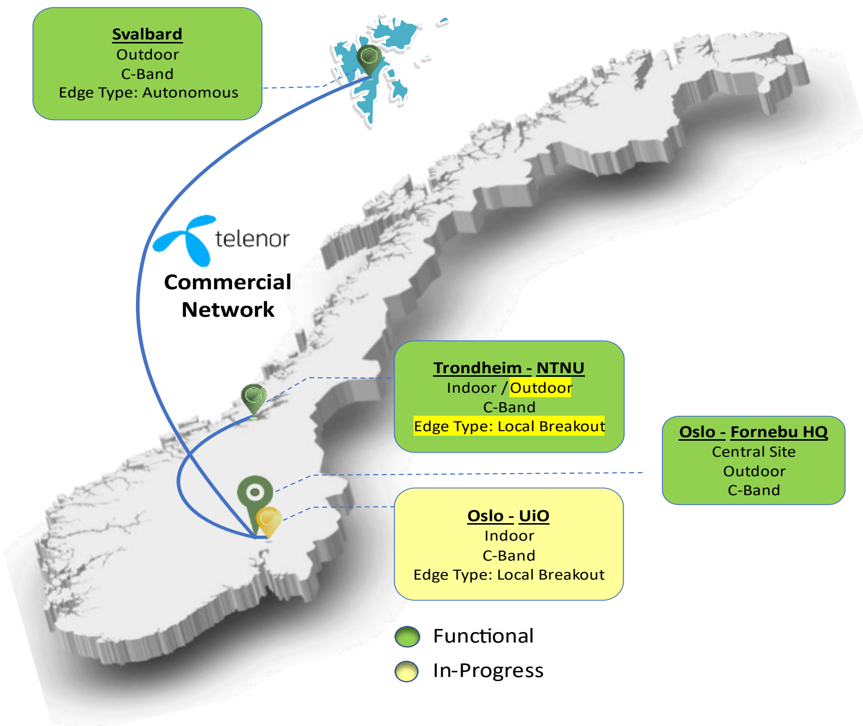

Figure 14 NGP site deployment status

3.1.1. Transport Network

The experimental/edge sites utilize existing Telenor's Norway commercial transport network to connect with data centre in central facility.

3.1.2. RAN

The facility constitutes multiple vendors regarding RAN equipment with Nokia, Huawei and Ericsson as key vendors. The experimental sites utilize existing Telenor's Norway transport network to connect with data center in central facility. Currently TNOR has 3 operating sites, i) at Fornebu (Central), ii) Svalbard and iii) NTNU Trondheim. All these sites are connected to central core in Fornebu. Table 2 provides information about spectrum and radio vendor whereas Figure 15 Outdoor radio site at Fornebu shows the outdoor radio site at Fornebu.

Figure 15 Outdoor radio site at Fornebu

Site	Band	Frequency (GHz)	Bandwidth (MHz)	Radio Hardware
Fornebu Outdoor	C-Band n78	3.3-3.4	80	Huawei
Svalbard Outdoor	C-Band n78	3.7-3.8	100	Ericsson
NTNU Indoor	C-Band n78	3.61-3.7	80	Ericsson

Table 2: Frequency spectrum/Vendor information of NGP radio sites

3.1.3. Core

The 5G core network solution is compliant with 3GPP 5GC service-based architecture and contains all the fundamental independent and reusable 5G core network functions (Access and Mobility Management Function (AMF), Session Management Function (SMF), Authentication Server Function (AUSF), Network Slice selection Function (NSSF), Network Repository Function (NRF), Unified Data Management (UDM), User plane Function (UPF)). The 5G SA core instances are deployed with instances from multiple vendors that include Oracle, ENEA and Casa Systems, as shown in Figure 16 NGP core Fornebu central site

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3.1.4. Network/Service Orchestration

Nokia's Network Function Virtualization Orchestrator (NFVO) - Nokia Cloud Operations Manager (NCOM) – is used for managing the 5G SA core components across all the sites and the public Cloud. As for the service orchestrator, Nokia's Orchestration Center (NOrC) is used. NOrC exposes interfaces such as TM Forum OpenAPIs for service ordering and service catalogue management.

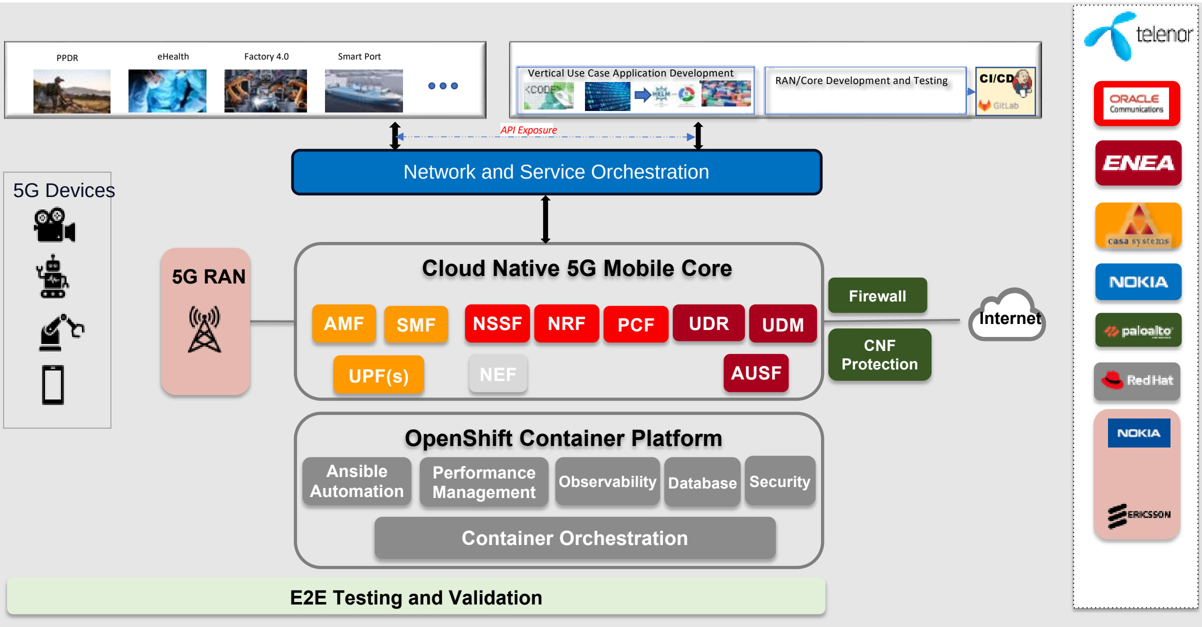

Figure 16 NGP core Fornebu central site

3.1.5. Security

The cloud native CNFs are deployed majorly in two classes, management class and service class. Management class consist of all the functions that are related to management such as NCOM and RedHat's ansible automation platform whereas the service class contains the rest of 5G core Network Functions (NFs). To isolate the traffic between different classes and to provide the zero-trust security, PaloAlto provides next generation firewall as a service with features such as Intrusion Prevention System (IPS), data leakage protection, application and protocol decoding, encrypted traffic inspection and signalling storm mitigation.

3.1.6. Open-Source Solutions

TNOR Open-Source Platform (OSP) is a supplementary testbed that could order and consume 5G network services from NGP's main platform (i.e., through Network Slice as a Service (NSaaS)). Alternatively, OSP can also use Telenor Norway's commercial network (4G/5G) or private 5G networks.

3.2. Network on Wheels

TNOR Network on Wheels (NoW) is standalone autonomous solution to provide on-demand 5G network coverage. NoW hosts the radio, core, and other applications as a one in all mobile solution that can be transported easily. It can be used in remote areas with no coverage or in areas where the connectivity infrastructure has been damaged due to natural disasters. Following are key advantages and functionalities of the NoW, however more details will be presented in the deliverable *D2.2 – Deployment and operation of 5G Private networks*.

- Coverage on demand with guaranteed Quality of Service (QoS).
- Compute at the Edge.
- Fully autonomous.
- Quick to deploy, simple to operate.
- Possibility to connect partner's edge.
- Secure and ruggedized.

3.2.1. RAN

Huawei provides the radio equipment, deployed in the NoW. The radio equipment constitutes Baseband Unit (BBU) model Double Sideband (DSB) 5900 inside the NoW as shown in Figure 17 Inside of NoW

and the Active Antenna Unit (AAU), model AAU5636 3400 MHz & AAU5649 3600 MHz deployed on a retractable antenna mast outside the network on wheels trailer as shown in Figure 18 NoW trailer with retractable antenna mast

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Figure 17 Inside of NoW

Figure 18 NoW trailer with retractable antenna mast

3.2.2. Core

The 5G core solution for the NoW is provided by Athonet as a software solution running on ruggedized server with minimum footprint (PriMo solution). The strict requirements of Public Protection Disaster Relief (PPDR) scenarios imply that not only the 5GC software (SW) is programmed to include self-healing and resilient capabilities, but also the hardware (HW) hosting the SW needs to be lightweight, robust, and resistant.

3.2.3. Backhaul Solutions

To provide the backhaul connectivity, the core is connected to Goodmill router equipped with commercial Telenor Subscriber Identity Module (SIM) card which is connected via Virtual Private Network (VPN) solution to the Telenor's Fornebu data centre. A satellite backhaul option will also be explored to complement the current solutions.

3.3. 5G Indoor Private Networks

TNOR has also deployed indoor 5G private network at different sites in Oslo, Norway (more information will be presented in the deliverable *D2.2 – Deployment and operation of 5G Private networks)*. These sites provide secure access to a specific set of corporate services, for different use cases, for example, a hospital environment where doctors, nurses, paramedic staff monitor patients by using different sensors connected to patients broadcasting securely over 5G and presented on a main dashboard.

Same than traditional 5G networks, the node hosts the private network, including the 5G NR, 5G core and similarly vertical applications all deployed in the edge server to provide different corporate services. Figure 19 High-level diagram overview of infrastructure deployed

shows the high-level diagram overview of infrastructure deployed.

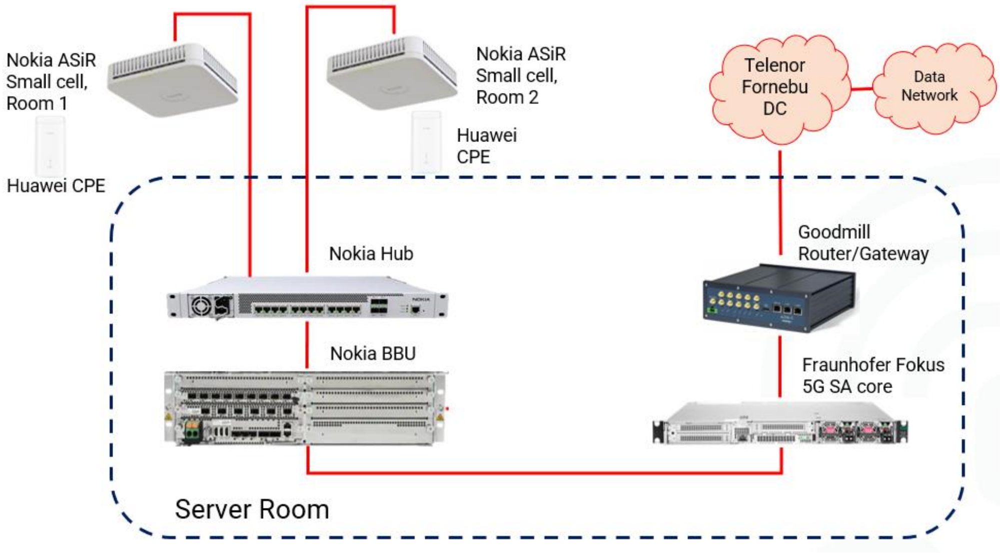

Figure 19 High-level diagram overview of infrastructure deployed

3.3.1. RAN

Nokia is used to provide the indoor 5G private network solution. The Nokia Airscale System module consists of following key components:

- NOKIA BBU: contains 2 cards, capacity card connected to the Nokia Hub and transmission card connected to the 5G core directly.
- NOKIA HUB is utilized to aggregate the traffic from different pico cells and forward it to the BBU. In total traffic from 12 pico cells can be aggregated.

- NOKIA ASiR picocells are the indoor remote radio head units to provide the coverage in different rooms.

3.3.2. Core

For different sites TNOR have utilized different cores. For the site presented above, Open5Gcore is provided by Fraunhofer FOKUS deployed on bare metal HPE DL110 telco server. All the 5G core components were deployed on the host machine without using network namespaces or any virtualization technique to achieve higher performance. The high level 5G core architecture is illustrated in Figure 20 Fraunhofer Fokus Core deployment at one of the indoor sites.

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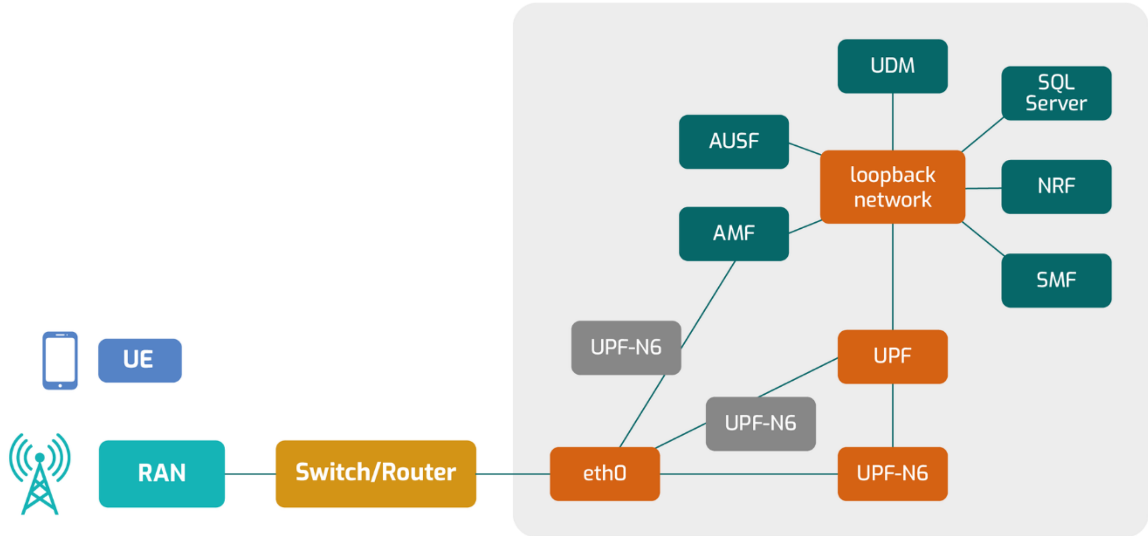

Figure 20 Fraunhofer Fokus Core deployment at one of the indoor sites.

3.3.3. Backhaul Solutions

To provide the Internet access the server is connected to Goodmill router equipped with commercial Telenor SIM card which is connected via VPN solution to the to the Telenor's Fornebu data centre.

3.4. Role of TNOR facility in COMMECT

Telenor Research and innovation is actively planning to collaborate with Telenor Norway in order to provide improved support for the Forestry industry. Specifically, Telenor Research is looking for an option to establish or utilize new outdoor/indoor RAN sites in the Kongsvinger area, where the COMMECT Living Lab has been established, to facilitate the remote control of forestry machinery. In addition, Telenor Research is also exploring the use of portable solutions to provide connectivity support during the logging process of the forest, further supporting situational awareness in Forestry.

Moreover, TNOR is also planning to set up an Indoor Private Network, with the aim of enhancing training experiences for the machinery operators through the use of Augmented Reality/Virtual Reality (AR/VR). This interactive approach will enable operators to experience the Forest habitat in a more immersive and engaging manner, thereby allowing them to better understand the routes to take and avoid damaging rare bio types in Forests. TNOR efforts to improve connectivity and facilitate the use of advanced technology in the forestry industry will undoubtedly bring about significant benefits, not only for the industry itself, but for society as a whole.

4. Connectivity Platform: 5Groningen Facility

The 5Groningen test facility has two field implementations, namely an indoor 5G network at a Warehouse facility and a 4G/5G Lab facility at the RUG campus (University of Groningen), see Figure 21. In the Warehouse 5G indoor test facility, see Figure 21 top-left, there are two core networks that are sharing the radio network according to the 3GPP standardized Multi Operator Core Network (MOCN) approach. One core network is from a mobile network operator and the second core network is from TNO. The 5G core implementation is virtualized and running on data center as well as edge cloud facilities. TNO's core network can also be connected with selected sites from commercial/production networks of mobile network operators.

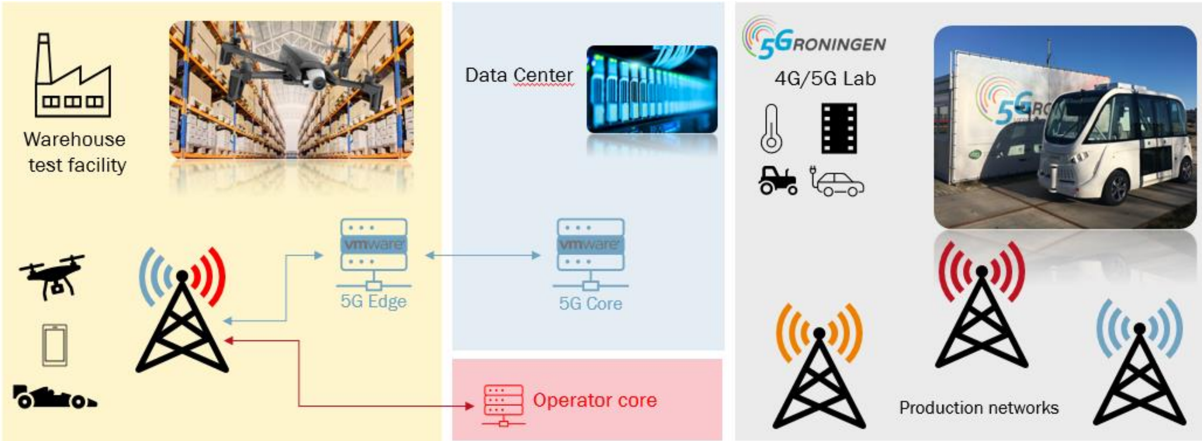

Figure 21: High-Level Overview of 5Groningen test facilities

4.1. RAN

Inside the warehouse, a complete 5G radio network has been installed, that consists of a passive Distributed Antenna System (DAS) antenna system on the walls and ceiling of the expedition hall and a cabinet in the server room with radio equipment connecting to mobile operator's and TNO core networks. The 5G radio network is based on Ericsson hardware with the following technical details:

- 5G band: 3.5 GHz (n78) with 100 MHz bandwidth test license.
- 4G band: 2.6 GHz (B7) with commercial license.
- Supports 4x4 Multiple Input Multiple Output (MIMO).
- Antennas: 6x passive directional on the wall, 6x passive omnidirectional on the ceiling.
- Ericsson RRU4422, RRU4415 and 2x6630 baseband.

4.2. Core Network

The TNO's 5G SA core is based on open source 5G core implementation Open 5GS (https://open5gs.org) running on the VMware resource clusters separated between two physical datacentre locations and communicates with the subscriber database in TNO's central location in The Hague. The user plane traffic of the 5G core is handled locally in the Warehouse 5G Edge network and directly connects / breaks out via the DN (Data Network) to a local application server (virtual or physical) that may run user applications. The control plane traffic that is responsible for managing (registering, establishing and maintaining) a network connection for the end-users is routed to the part of the 5G core network which is situated at the RUG data centre (University of Groningen). The 5G edge network also directly connects to the 5G Radio, which enables a fully SA 5G network.

The open source 5G core is deployed on a cloud-native platform as containers with Kubernetes (K8s) orchestration, are able to connect to the 5G Service Platform (5GSP) platform and support multiple slices to the shared RAN. It is worth noting that the set-up is a truly open-source network and also supports the NSSF. Figure 22 visualizes the 5G core architecture with an example of network slicing configuration.

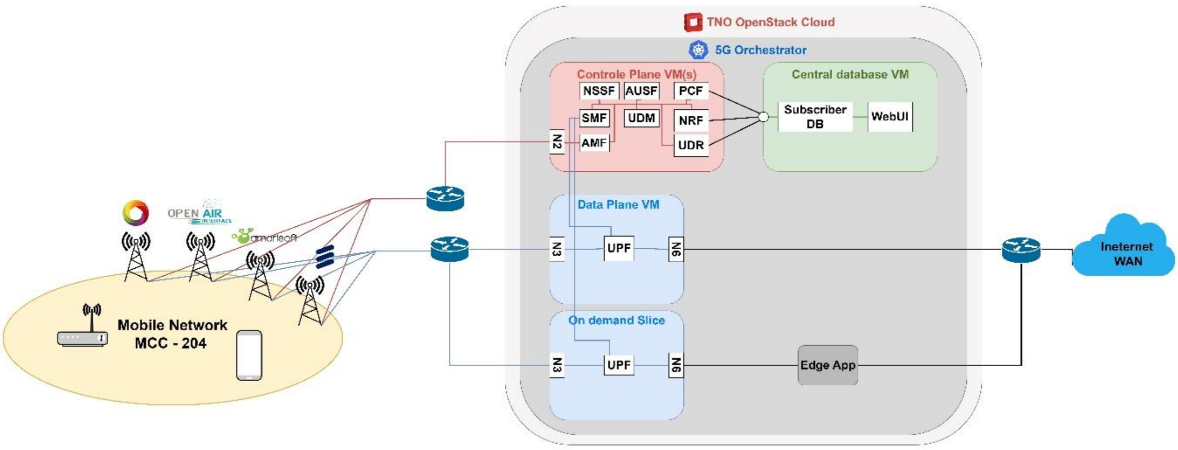

Figure 22: TNO 5G Core Architecture with example network slicing configuration

4.3. MANO

The TNO's 5G SA core is orchestrated using K8s and Helm Chart. All 5G network functions are containerized and can be used separately of as a part of a bigger deployment. To make deployment of 5G core easy and configurable the entire network is described using K8s resources (Deployments, Services, Secrets, Custom resource Definition (CRD), etc.) and divided into smaller Helm charts, each one representing single network functions, for example, AMF. These Helm charts are then wrapped into a bigger Chart that represents the entire Core network. Configuration of 5G core is leveraging Helm Value files, meaning that a change of a specific parameter corresponds to reconfiguration of 5G network (adding slices, modifying Access Point name (APNs) etc).

4.4. NFVI

One of the highlights of TNO's 5G SA core is its eXpress Data Path (XDP) accelerated UPF. The goal of the acceleration was to increase throughput and reduce the latency in 5G network. The results of acceleration are included on Figure 23.

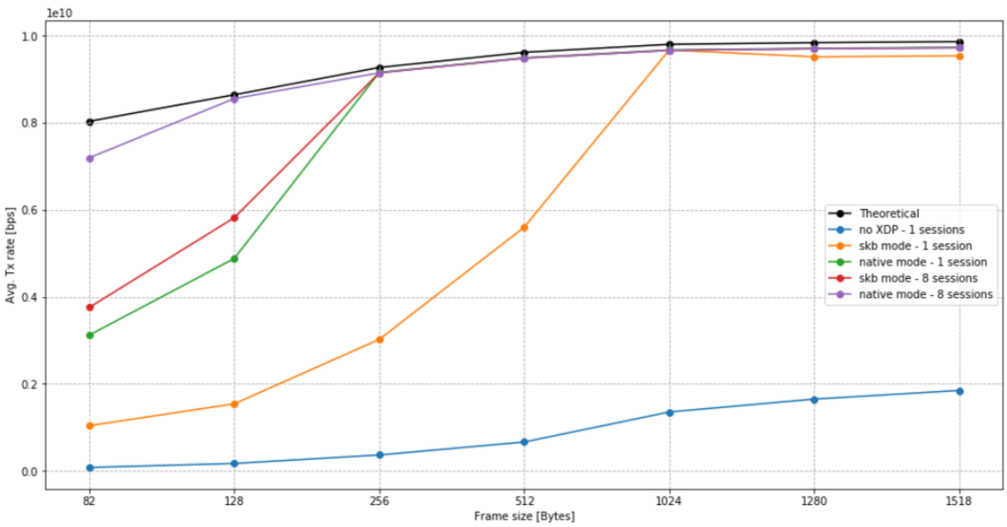

Figure 23: UPF traffic improvement in terms of throughput.

4.5. Local private network – Amarisoft

For creating private 5G networks in the field there is also Amarisoft's portable 5G solution that contains a whole network in a box (for example, 5G RAN and 5G Core), see Figure 4.

The 5G RAN configurations supported are 2x2 MIMO in one or two cells with Frequency Division Duplex (FDD) or Time Division Duplex (TDD) or only one cell with 4x4 MIMO (in downlink). The support is for band n78 and up to 100 MHz. Furthermore, the 5G Core is SA capable.

More information will be provided in the deliverable *D2.2 – Deployment and operation of 5G Private networks*.

4.6. 5G Terminals

The following terminals are available:

- Modem:
  - Quectel RM500, RM502.
- UE:
  - Quectel USB dongle, PCIE-CARD EVB Q1-A5814.
  - Nighthawk M5 MR5200.
  - OnePlus Nord CE 5G.
  - OnePlus 10 Pro.
  - Fibocom FM150.

4.7. Role of 5Groningen Facility in COMMECT

The envisaged usage of TNO's test facilities within COMMECT's Danish LL is illustrated in Figure 24 focusing on the specific use case for off- and on-loading of livestock from/to- a transportation vehicle in a remote farm location. The portable Amarisoft base station will be placed/installed at the desired farm location in order to provide for example, a 4G/5G radio coverage. The Amarisoft base station will be connected to TNO's 5G core implementation (or alternatively using Amarisoft's own 5G Core) such that a local Non-Public-Network (NPN) can be created on-demand. A video surveillance device, for example a video-camera enabled for 4G/5G communication or a combination of a 4G/5G phone connected to a video camera (for example, GoPro), will be installed on the transportation truck. This video surveillance device will be connected to the local NPN created at the farm location, for example, for monitoring the livestock off- or on-loading process from a remote location. If during the course of the COMMECT project no test frequency licenses can be arranged and the selected farm location, then this set-up can use 5 MHz unlicensed band at 1800 MHz (for example, the so-called guard DECT band) for 4G radio coverage or, in the worst case, the whole test set-up can be re-fitted with use of Wi-Fi networks.

In order to investigate different conditions with respect to farm's backhauling connectivity we plan to connect the locally created NPN network via a fixed line, terrestrial microwave or a satellite backhaul link with the internet.

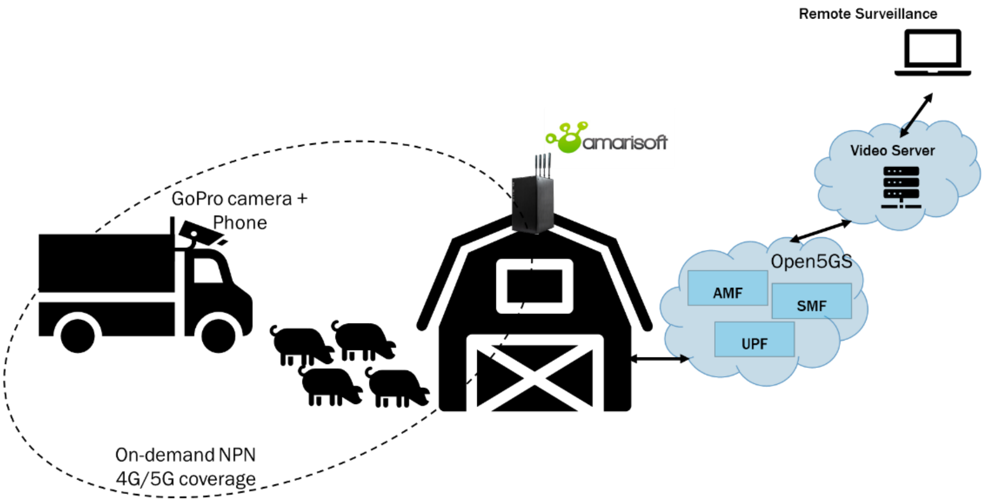

Figure 24: Concept deployment of TNO's 5G facilities within COMMECT's Danish LL

5. Connectivity Platform: AAU 5G Smart Production Lab

The AAU 5G Smart Production Lab is a two-hall research lab of more than 1200 m^2 located at Aalborg University, in Denmark [2]. As shown in Figure 25, the lab resembles a realistic industrial environment with access to a wide range of manufacturing and production equipment such as production line modules, Autonomous Mobile Robots (AMRs), autonomous forklifts, robotic arms, welding machines, etc. Additionally, the lab is equipped with network deployments from different technologies such as IWLAN, Wi-Fi 6, MuLTEfire, and different configurations of LTE and 5G. These technologies will be further described in the following sections and are available to the COMMECT partners for testing and validation of the different solutions proposed during the project. A high-level overview of the network infrastructure available in the AAU 5G Smart Production Lab is shown in Figure 26. Three *communication islands,* with Access Points (APs) and cells from the different technologies are distributed along the two lab halls, providing coverage to the whole industrial facility.

Figure 25: Hall 1 at AAU 5G Smart Production Lab.

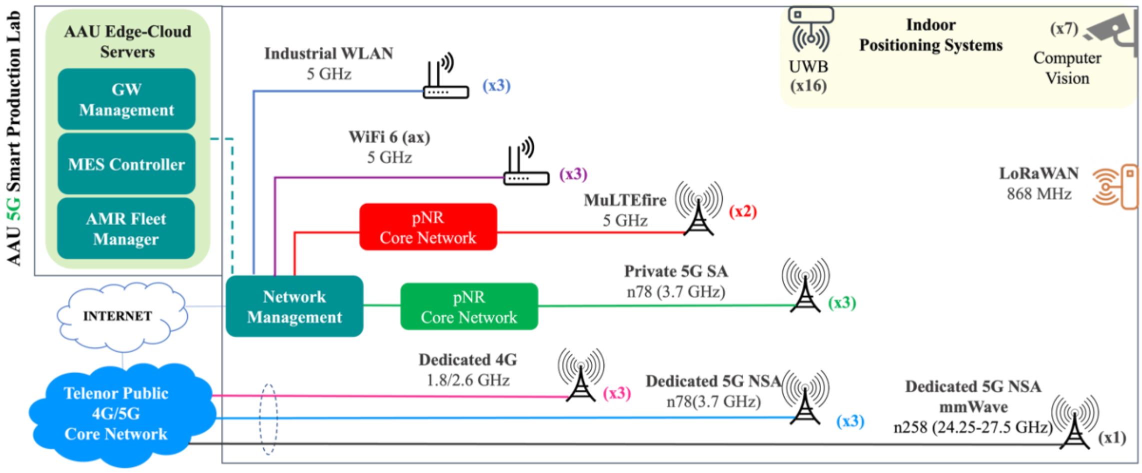

Figure 26: High-level overview of the network infrastructure and positioning systems deployed at the AAU 5G Smart Production Lab.

5.1. Unlicensed Spectrum Technologies

The AAU 5G Smart Production Lab counts on different wireless technologies that operate in the unlicensed frequency bands, where the spectrum is shared with other networks. These technologies have lower cost than those operating in the licensed spectrum but show higher congestion and reduced security, leading to reduced performance as compared to the licensed spectrum. For all technologies, the spectrum is coordinated with other Wi-Fi networks available at Aalborg University so that interference is avoided as much as possible, guaranteeing the appropriate conditions for experimental research.

Specifically, the following networks are available:

- LoRaWAN: long range and low power consumption, has a great potential in industrial scenarios depending on the require loop latencies, operating in the 868 MHz frequency band with 125 kHz bandwidth.
- Wi-Fi 6: IEEE 802.11ax deployment where spectrum and traffic patterns are coordinated for optimization. There are three APs in the lab. Each AP operates on their own 5 GHz frequency channel with 20 MHz bandwidth.
- Industrial WLAN: IEEE 802.11ax wireless LAN for industries extends WiFi 6 capabilities, allowing higher data rates and improving performance and efficiency. There are three access points in the lab, operating at 5 GHz.
- MuLTEfire: combining high performance of LTE with the low complexity deployment of WiFi, the lab includes a MuLTEfire deployment with a private core with 3 radio cells, operating at 5 MHz with 100 MHz bandwidth.

5.2. Licensed Spectrum Technologies

Technologies in the license spectrum provide enhanced performance, efficiency and security, and reduced interference due to spectrum coordination. The AAU 5G Smart Production Lab counts on the following technologies, which are available for testing and evaluating the potential solutions for the different COMMECT use cases:

- Dedicated 4G LTE: dedicated 4G LTE operator-managed network slice. A dedicated Base Station (BS) inside the lab connected to the public core. Three cells, operating at 1.8 GHz/2.6 GHz with 20 MHz and using TDD.
- Dedicated 5G NSA: Located inside the lab and connected to the public core of a Danish operator with dedicated core-RAN dark fiber WAN connection. There are two options:
    - FR1: 5G small cell solution with three radios configured as a single cell and 4x4 MIMO configuration. Operating in the 3.7 GHz frequency band (n78) with 100 MHz bandwidth, using TDD.
    - FR2: Radio module and antenna extension module with 32 beams configuration, and up to 192 elements with dual polarized 12x8 arrays. Operating in the n258 frequency band (24.25 GHz – 27.5 GHz) with 100 MHz bandwidth, using TDD.

For both cases:

- LTE anchor bands: 1 (2100 MHz), 3 (1800 MHz), and 7(2600 MHz).
- TDD DL/UL (Downlink/Uplink) ratio is set to 3/7, but it is configurable.
- Subcarrier spacing for NR: 30 kHz.
- Release 15 with some software early upgrades for higher releases.

- Private 5G SA: local private deployment consisting of a small cell solution with three radios and a private core with integrated edge-cloud. Operating in the n78 frequency band (3.7 GHz) with 100 MHz bandwidth, using TDD.

5.3. 5G Terminals

The following terminals are available for testing:

- Multiple cellular modems of the following models:
    - QUECTEL RM500Q (Rel. 15, FR1, Qualcomm chipset).
    - QUECTEL RM520N-GL (Rel. 16, FR1, Qualcomm chipset).
    - QUECTEL RM510Q-GL (Rel. 16, FR2, Qualcomm chipset).
    - SIMCOM M8202G (Rel. 15, FR1, Qualcomm chipset).
    - SIMCOM M8300 (Rel. 15, FR1 and FR2, Qualcomm chipset).
    - Fibocom FM350-GL (Rel. 15, FR1, MediaTek Chipset).
- 2xUEs:
    - OnePlus 9 Pro.

5.4. Multi-Access Gateway

The Multi-Access Gateway (MAGW) designed at Aalborg University allows seamless and technology-agnostic wireless control communication [3].

The main element of the MAGW is an ARM-based Gateworks GW6405 industrial computer [4]. This computer has a small size, and support for up to four mini-PCIe extension cards, 5 ethernet ports that allow connection of different devices, for example, cellular modems, WiFi cards, and ethernet-based communication devices. The computer also has integrated Global Positioning System (GPS) antenna port, which allows recording the position of any given measurement sample. An updated version of the MAGW uses an Intel Next Unit of Computing (NUC) 12 Pro Kit [5] as mini-PC due to its higher computational capabilities, and its flexibility to install a wide variety of memory, storage, and operating systems.

The MAGW includes the *mpconn* flexible multi-connectivity tunnelling program [6] loaded in the industrial computer. This tool supports Layer 2 and Layer 3 tunnelling over several transport protocols. Current supported features are:

- Layer 2 tunneling (Ethernet over Transport layer).
- Layer 3 tunneling (IP over Transport layer).
- UDP remote transport.
- Multi-connectivity via packet duplication on multiple network interfaces.

Therefore, this tool allows to simplify the implementation of multi-connectivity by performing packet duplication at Transport layer. This allows to evaluate the benefits of multi-connectivity between different devices and/or technologies without the need of modifying the lower layers.

A picture of the MAGW setup with the Gateworks Mini-Personal Computer (PC) is shown in Figure 27, where, for example, two cellular modems with SIM cards from different operators would allow us to evaluate the individual performance of both operators, as well as the advantages provided by performing multi-connectivity between them.

Figure 27: Multi-Access Gateway.

5.5. Starlink Satellite User Terminal

The AAU 5G Smart Production Lab also counts on a round-shape commercial Starlink Gen-1 User Terminal (UT)[2], shown in Figure 28. Despite this antenna is meant for meant for providing static coverage, it has also been tested under mobility conditions, offering the opportunity of using it to test satellite-based connectivity solutions for mobility scenarios.

Figure 28: Starlink satellite UT in the roof of AAU 5G Smart Production Lab.

[2] www.starlink.com

At the time of writing, Starlink provides the most advance broadband satellite internet. The Starlink satellite constellation consists of more than 3500 satellites launched, and nearly 12000 satellites are planned to be deployed. Starlink uses the Ku-band for the user communications, and GW communications will be carried out in Ka-band. Specifically, for user communications, the 10.7–12.7 GHz band is used for downlink and the 14.0–14.5 GHz band is used for uplink. Additionally, the Starlink constellation uses Laser Inter-Satellite Links, which allow the satellites to establish laser connections between each other, regardless of if they are in the same or in different orbital planes [7, 8].

5.6. Role of AAU 5G Smart Production Lab

Two elements available in the AAU 5G Smart Production Lab facilities will mostly be used in the COMMECT project: the MAGW and the Starlink antenna. These will be used to evaluate connectivity solutions for the Danish Living Lab *(Connected Livestock Transport).* The MAGW, will allow us to perform a coverage analysis on the main transport routes of user, and validate multi-connectivity between different operators and technologies as a solution to provide continuous coverage. Similarly, the Starlink antenna will be used to obtain empirical performance results for cellular-satellite multi-connectivity as potential solution to provide over-the-route seamless connectivity.

Additionally, the different technologies currently deployed in the AAU 5G Smart Production Lab are available for any COMMECT partner that may need them for testing and validating the solutions proposed for other Living Labs.

6. Connectivity Platform: Turkcell IoT XG Test Platform

Turkcell IoT XG test platform is located in İstanbul Kartal Turkcell headquarter. Turkcell conducts tests and trials with candidate vendors at either agreed locations or directly at its Captive IoT XG test platform which hosts samples of network components of all generations. The core network components at the Captive IoT XG test platform are connected to radio access units residing onsite or at remote locations like İzmir and Antalya where the COMMECT Living Lab Türkiye Smart Olive Tree Farming is located. Figure 29, Figure 30 and Figure 31 show the Turccell IoT XG test platform room, system room and the smart olive tree farming installation, respectively.

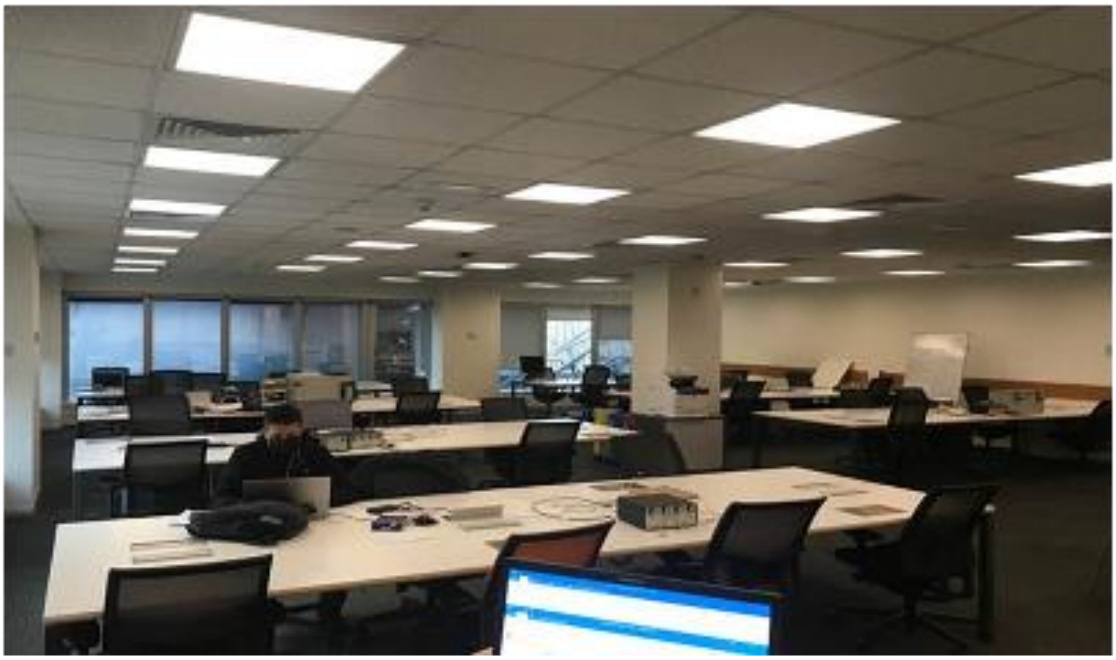

Figure 29: Turkcell IoT XG Test Platform Test Room.

Figure 30: Turkcell IoT XG Test Platform System Room.

Figure 31: COMMECT LL Türkiye Smart Olive Tree Farming Installation.

6.1. RAN

NB-IoT and enhanced Machine Type Communications (eMTC) are cellular Internet of Things radio access technologies specified by 3GPP to address the fast-expanding market for low power wide area connectivity. Its specification started from 3GPP Release 13. Non-Terrestrial Network (NTN) support comes in 3GPP Release 17 to achieve global coverage and wide adoption of IoT services. The following NB-IoT features are supported for COMMECT Living Lab Türkiye smart olive tree farming:

- Power Save Mode (PSM).
- Extended Discontinuous Reception (eDRX).
- Paging.
- Cell Reselection.
- Support for extended coverage.
- Power class.
- Rate control mechanisms.
- Home Subscriber Server.
- Multi Frequency Band.

The following eMTC features are needed for COMMECT Living Lab Türkiye smart olive tree farming tests:

- PSM.
- eDRX.
- High Latency Communication.
- Support for extended coverage.
- LTE-M Half Duplex Mode/Full Duplex.
- Support of Category M1 device.
- Voice over LTE (VoLTE) support.
- Short Message Service (SMS).
- Connected Mode Mobility.

6.2. Core Network

Turkcell core network includes Mobility Management Entities (MMEs) support of the NB-IoT RAT type. It enables the MME to handle RAT-type NB-IoT internally and to send the NB-IoT RAT type to the Serving Gateway (SGW), Packet data Network Gateway (PGW), and Home Subscriber Server (HSS). This enables full system support for UEs using NB-IoT access. The basic diagram of the Turkcell IoT XG test platform's shared in Figure 32. Supported MME features:

- Low Complexity UE Support.
- Coverage Extension Support, LTE.
- eDRX for LTE and NB-IoT.
- Power Saving Mode for LTE and NB-IoT.
- PSM & eDRX Interworking.
- Data over Non-Access Stratum (NAS).
- Configurable Battery Saving using eDRX and PSM.
- Location Services

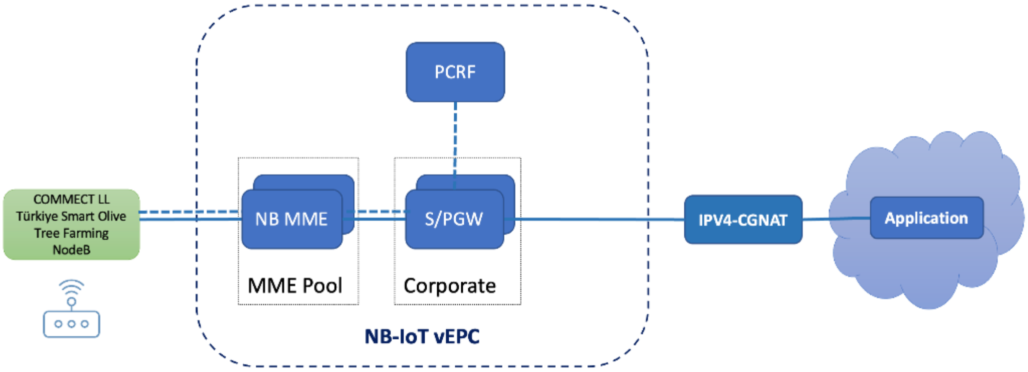

Figure 32: Turkcell IoT XG Architecture.

Besides MME features, the following SGW/PGW ones will be used in COMMECT Living Lab Türkiye smart olive tree farming:

- NB RAT Type Support.
- PGW Congestion Control.
- APN Based NB-IoT Access Rate Control.
- Serving Public Land Mobile Network (PLMN) Based NB-IoT Access Rate Control.
- Data Transmission with Control Plane Optimization.
- Data Transmission with User Plane Optimization.

6.3. Role of Turkcell IoT XG Test Platform in COMMECT

Turkcell IoT XG test platform works on different radio access technologies that operate in multi-vendor environments. In COMMECT LL Türkiye smart olive tree farming (see Figure 31), eMTC and NB-IoT radio access technologies will be tested for different 3GPP releases. The sensors/devices and features need to be tested in the Turkcell IoT XG Test Platform before live network integration. To guarantee constant and reliable measurements in the COMMECT project, the approved and tested sensors/devices will be used for different use cases in various radio conditions.

7. Connectivity Platform: Serbian Living Lab

The agriculture sector in Serbia plays a crucial role in the country's economy and employment, particularly in the Vojvodina province. Land suitable for agriculture represents around 70% of total area, mostly located in Vojvodina province, northern part of Serbia. The current agriculture practice still mostly relies on experience influencing on negative environmental impact including soil degradation and biodiversity loss. Improving agriculture practice by introducing digital services will lead to less pesticide usage, optimal water usage, less gas emission and consequently less negative environment footprint. Introducing digital solutions into agriculture practice is planned through the Living Lab that will be established in Gospodjinci village, located in Vojvodina province, surrounding with nature park where agriculture has a huge impact on the environment. The Living Lab will utilize mobile solar generators, edge technology, and renewable energy sources to establish connectivity based on LPWAN network that covers extended rural areas. Additionally, sensors for environmental and soil parameters, air quality, noise level, and cameras will be installed to provide real-time insights into environmental conditions throughout the agriculture and nature park area.

Figure 33 shows a high-level of the Serbian Living Lab architecture.

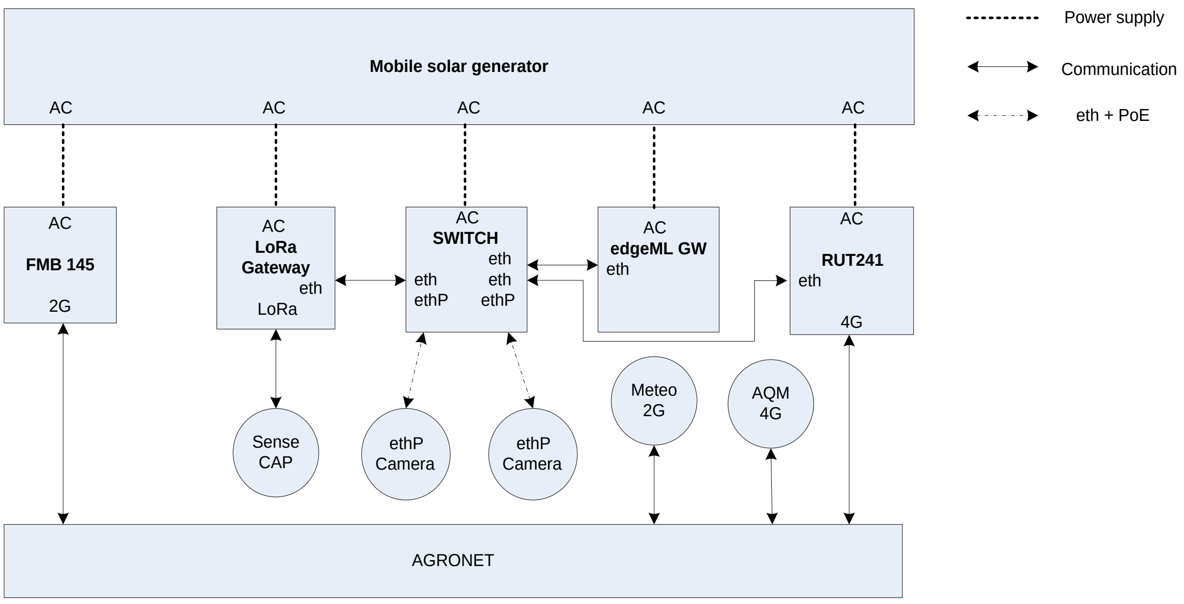

Figure 33: Serbian Living Lab architecture

Mobile solar generator is used to provide power supply to the communication network elements. The following devices are connected to mobile solar generator for power supply: FMB145, LoRa GW, switch, egdeML GW and RUT 241. FMB145 device collect GPS data about mobile solar generator position and send this data to Agronet platform (AgroNET (www.digitalfarming.eu) is a digital farming platform with a set of turnkey services designed to support more efficient farm operation, The target areas are vineyards, orchards, poultry farms and farm supply chain) via Global System for Mobile communications (GSM). SenseCAP is battery poweredand send data about soil to LoRa GW which are then transferred via switch and RUT241 to Agronet platform. Cameras are connected to switch and get supply via Power over Ethernet (PoE) from switch. Picture from camera will be processed in the edgeML GW and the results will be sent to Agronet platform via RUT 241. RUT 241 sends data via 4G network to Agronet platform. Meteo station measures precipitation, air temperature, relative humidity, leaf wetness, global radiation, wind speed, wind direction and send data directly to Agronet platform via GSM. Air quality monitoring device measures Carbon Dioxide (CO_2), Nitrogen Dioxide (NO_2), Particulate Matters (PMs) and noise and sends data directly to Agronet platform via 4G.

7.1. RAN

The Serbian connectivity platform includes some RAN networks:

- LoRa network (EU 868):
- LoRa GW for sensors data collection.
- LoRa/LoRaWAN sensors for soil moisture monitoring.
- GSM network (GSM 900, GSM 1800).
- 4G network (800 MHz, 1800 MHz bands, 2100MHz).

7.1.1. LoRa Gateway

The SenseCAP GW - LoRaWAN is a central device designed for collecting and transmitting data from different SenseCAP sensors to the cloud platform through cellular LTE or Ethernet connections. The device is based on the LoRa Application protocol, which makes it suitable for low-power consumption and long-range environmental data collection. The GW is equipped with a high-performance processor and a LoRa chip that ensures robustness and high performance in large-scale networks. The whole network is established with mutual authentication and encryption to enhance the security of data transmission. The device is suitable for industrial applications in severe indoor and outdoor environments, as it has an IP66 enclosure and supports an extended operating temperature range. It comes with a 4G LTE module and an external 4G antenna, supporting non-Carrier Aggregation (CA) Category (Cat) 4 FDD and TDD with maximum data rates of up to 150Mbps for downloads and 50Mbps for uploads. The device is also equipped with Light-Emitting Diode (LED) indicators, grounding options, and certifications such as Conformité Européenne (CE), Federation Communication Commission (FCC), and Restriction of Hazardous Substances (RoHS). Overall, the SenseCAP GW - LoRaWAN is a reliable and powerful device that can be used in smart agriculture, smart city, and other remote monitoring scenarios that require long-range data collection and transmission.

Figure 34: LoRaWAN GW

Main features:

- It collects data from different sensors and transmits the data to the cloud platform via cellular LTE or Ethernet.
- Equipped with a high-performance processor AM3358 and telecom-operator-level Long Range chip SX1301, this device ensures robustness and high performance in large-scale networks.
- It supports mutual authentication and encryption throughout the network to increase security.
- The GW is designed with an IP66 enclosure and supports an extended operating temperature range, making it suitable for industrial applications in both indoor and outdoor severe environments.
- It has a LoRa Power Output of 25dBm and LoRa Sensitivity of -139dBm (SF12BW125).
- The device features Ethernet 100Mbps FE (RJ-45) and 4G Band including LTE-FDD, LTE-TDD, Wideband Code Division Multiple Access (WCDMA), and GSM.
- The GW supports non-CA Cat 4 FDD and TDD with LTE-FDD Max 150Mbps (DL), Max 50Mbps (UL), and LTE-TDD Max 130Mbps (DL), Max 30Mbps (UL).
- It has an operating temperature range of -40 ℃ to +70 ℃, and its dimensions are 256mm * 160mm * 81mm with a weight of 777g.

7.2. Mobile Solar Generator

Mobile solar generators will be used to replace fossil fuel generators and thus contributing to decreasing of noise and CO2 emission. These generators will be able to provide energy for required devices necessary for data gathering and network infrastructure without causing environmental pollution. Mobile solar generators are designed as foldable tractor trailers, which can generate 5 kW to 30 kW of electricity depending on configuration**.**

Figure 35: Mobile solar generator

The mobile solar generator is intended for use in production plots, orchards, vineyards, livestock farming facilities for powering different consumers (such as irrigation systems, stalls, shepherd's huts, etc.). Thanks to its mobility, the solar generator can be used to power different consumers at different locations. A continuous source of energy during the night or cloudy days is enabled by a battery that is added as part of the system. Main technical characteristics:

- Solar generator power: up to 30 kW, three-phase.
- Solar panel type: Monocrystalline.
- ON grid / OFF grid operation possibility (hybrid inverter).

- Output power of the inverter in ON grid mode is equal to the output power of the solar generator.
- Inverter protection IP65.
- Output voltage 230 V.
- Frequency 50 Hz.
- Battery voltage: up to 24 V.
- Battery capacity: up to 300 Ah.
- Possibility of expanding battery capacity.
- Hydraulic lifters enable lowering and raising of side panels and tilting of the platform with panels in relation to the horizontal plane.

7.3. Connectivity Devices

7.3.1. Dahua Camera: DH-SD22404-GN

Featuring powerful optical zoom and accurate pan/tilt/zoom performance, the camera provides a wide monitoring range and great detail. The camera delivers 4MP resolution at 25/30fps. The camera is equipped with smooth control, high quality image, and good protection, meeting compact size demands of video surveillance applications.

Figure 36: DH-SD22404T-GN

7.3.2. edgeML: JetsonXvaier 16GB

reComputer J20-series are compact edge computers built with NVIDIA advanced Artificial Intelligence (AI) embedded systems: Jetson Xavier NX and Seeed reference carrier board (J202). With rich extension modules, industrial peripherals, thermal management combined with decades of Seeed's hardware expertise, reComputer Jetson is ready to help you accelerate and scale the next-generation AI product emerging diverse AI scenarios.

Figure 37: Jetson Xvaier 16GB

Jetson Xavier NX delivers up to 21 Tera Operations Per Second (TOPS), making it ideal for high-performance compute and AI in embedded and edge systems. You get the performance of 384 NVIDIA CUDA® Cores, 48 Tensor Cores, 6 Carmel ARM Central Processing Unit (CPUs), and two NVIDIA Deep Learning Accelerators (NVDLA) engines. Combined with over 59.7GB/s of memory bandwidth, video encoded, and decode, these features make Jetson Xavier NX the platform of choice to run multiple modern neural networks in parallel and process high-resolution data from multiple sensors simultaneously.

The Seeed reference carrier board provides several connectors with industry standard pin outs to support additional functionality beyond what is integrated on the main platform board. This includes USB 2.0: Type C Connector, USB 3.0: 2 x Type A Stacked Connectors, Gigabit Ethernet: RJ45 Connector, HDMI / DP: HDMI Type A and Display Port Stacked Connector, M.2, Key E Socket and M.2, Key M Socket.

Internal SSD with 256GB capacity will be added to edgeML Jatson Xvaier.

Figure 38: NVMe M.2 2280 Internal SSD

7.3.3. TELTONIKA FMB125 (Dual SIM tracker with RS232, RS485 Interfaces)

Teltonika FMB125 is SPECIAL tracker with external GNSS, internal GSM antennas, Bluetooth connectivity and backup battery. FMB125 is designed for communication with various third-party RS232 or RS485 devices, like digital fuel sensors, Garmin navigation device, Radio Frequency Identification (RFID) reader and much more. It is also excellent for refrigerated transport, because it has extended input/output set and 1-wire interface for temperature monitoring. With Teltonika CAN adapters, FMB125 can be even used in agriculture or construction & mining.

Figure 39: TELTONIKA FMB125

7.3.4. TELTONIKA RUT241

RUT241 is industrial cellular router. Compact, robust and powerful device tailored for industrial M2M/IoT applications. RUT241 is the modified version of RUT240. Equipped with 4G LTE, Wi-Fi, and two Ethernet ports, this router offers connection continuity with a backup through automatic failover. Stable connectivity is ensured with WAN failover, while the RutOS software meets the highest security standards. Compatible with Remote Management System (RMS).

Figure 40: TELTONIKA RUT241

RUT241 is widely used for 4G backup, Remote Connection, Advanced VPN, and tunnelling services in IoT networking solutions. WAN failover ensures automatic switch to alternative backup connection in case of any connectivity issues. The Wi-Fi is functional in both: Access point and Station mode at the same time

Key features:

- Mobile 4G/LTE (Cat 4), 3G, 2G.
- CPU Mediatek MIPS 24Kc 580 MHz.
- Storage 16 MB, SPI Flash.
- Memory 128 MB, DDR2.
- 1 x SIM slot (Mini SIM – 2FF), 1.8 V/3 V, external SIM holder.
- 2 x SMA for LTE, 1 x RP-SMA for Wi-Fi Antenna connectors.
- Ethernet 2 x RJ45 ports, 10/100 Mbps.
- Wi-Fi IEEE 802.11b/g/n, Access point (AP), Station (STA).
- Operating temperature -40 °C to 75 °C.

7.3.5. Switch: DGS-1100-08P

The Dahua PFS3010-8ET-96-V2 is a network switch that enables to connect multiple network devices together and allows them to communicate with each other. Specifically, this switch has 8 ports that support Fast Ethernet and PoE, which means it can supply power to connected devices such as IP cameras or wireless access points through the Ethernet cable, without requiring a separate power source. It also supports different PoE standards, including Hi-PoE, IEEE 802.3af, IEEE 802.3at, and IEEE 802.3bt.

Figure 41: DAHUA PFS3010-8ET-96-V2 8port Fast Ethernet PoE switch

It is powerful and flexible networking solution for small, medium, and enterprise businesses with features:

- 8 x 10/100 Mbps PoE ports.
- Supports Hi-PoE, IEEE 802.3af, IEEE 802.3at, IEEE 802.3bt.
- Switch capacity 5.6 Gbps.

7.4. Role of Serbian Connectivity platform in COMMECT

Main purpose of the Serbian Connectivity Platform is to provide the necessary infrastructure for data exchange between the different components, such as the various sensors, weather station and cameras for video recording. In addition to providing the infrastructure, the Serbian Connectivity Platform also plays an important role in data processing and management. It ensures that the data is properly collected, processed, and stored, and that it is easily accessible to all the relevant stakeholders in the project. Furthermore, it is responsible for ensuring the security and privacy of the data that is collected and exchanged within the different stakeholders. It implements various security measures, such as encryption and authentication, to protect the data from unauthorized access or manipulation. Overall, the Serbian Connectivity Platform will enable the seamless flow of data and information between the different stakeholders involved in the digitization of agriculture in Gospodjinci.

8. Cross Connectivity Platforms

In time of writing this section not all information has been fully specified and available. This section describes the ambitions and future plans in terms of interconnection and interworking among the connectivity platforms of the COMMECT project.

8.1. Luxembourg Facility and 5Groningen Facility

The Luxembourg Facility will be satellite interconnected with the 5Groningen Facility (located at TNO's premises in Netherlands) and the SES's teleport Facility-site located in Betzdorf (Luxembourg) as depicted in Figure 42.

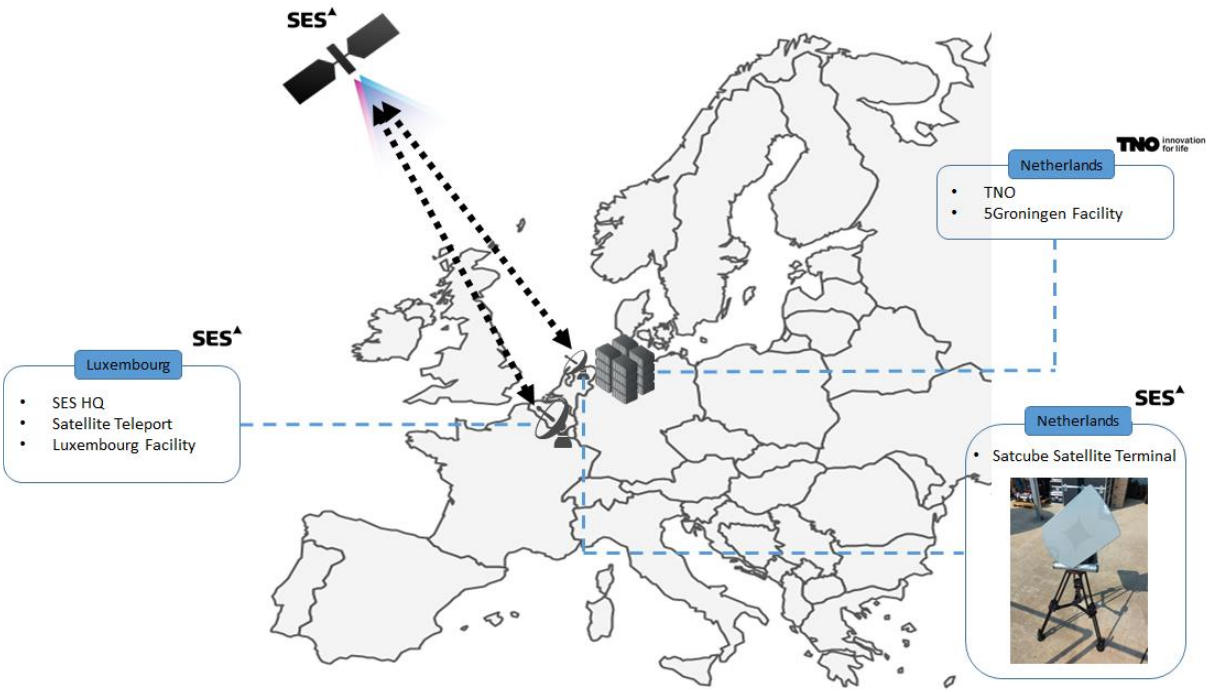

Figure 42: Satellite interconnection between Luxembourg Facility and 5Groningen

Provided services

It is widely recognized that, in order to be successful and meet user demands, the 5G infrastructure will be an ecosystem of networked networks, utilizing different and complementary technologies. The satellite role in the 5G ecosystem is proven on the basis of its benefits and its integration in the overall network. Often, satellite remains the only connectivity solution in areas where existing terrestrial infrastructure is insufficient. Satellite communication systems are easy to set up and use, and their portability allows for quick deployment. With modern end-to-end solutions, connectivity is plug-and-play, simplifying usage even further. For these reasons, in the COMMECT project, in areas with poor coverage for the loading/unloading of the animals, the Luxembourg Facility led by SES and 5Groningen Facility led by TNO, will investigate the deployment of a local, temporal broadband network including the option to have satellite backhaul.

Interconnection Requirements

The availability of a backhaul link for a 5G base station (or gNB according to 3GPP terminology) is an important enabler for providing local 5G coverage. In a 5G SA deployment the backhaul link should provide support for the N3/N2 interfaces between the 5G base station and the 5G core network[3]. The communication requirements for these N2/N3 interfaces between the 5G base station and the core network are, for example, up to 10 ms delay and few (tens) Gbps throughput depending on the amount of spectrum used at the 5G base station and its (massive) MIMO antenna Tx/Rx capability. If a satellite link is used for N2/N3 interface backhauling then the delay requirements dictate usage of Low Earth Orbit (LEO) satellite solution, however, in the COMMECT project GEO satellite solution will be provided where the round-trip time delay is around 600 ms. Additionally, the throughput requirement of few Gbps would make the satellite backhauling solution rather costly.

For the purpose of testing local 5G coverage at, for example, farms in rural areas in the context of COMMECT and including satellite links in the overall solution, the plan is to have a local 5G solution that includes both RAN and the 5G core functionalities while the satellite link only provides connectivity between the 5G network and internet for the application data. For example, if we consider a video surveillance application for the local 5G network then the satellite communication link requirements can be relaxed to, for example, few tens/hundreds of milliseconds delay and up to, for example, 10 Mbps throughput.

[3] N3 is the interface between the gNB and the User Plane Function (UPF), while N2 is the interface between the gNB and the Access Management Function (AMF) in the 5G core network.

9. Conclusions

This document (which is the first version while more information will be provided in the second version), *D2.1 – 5G Connectivity Platforms*, outlines the connectivity platforms that will be employed in the COMMECT project. These platforms have been designed to cater to the varied needs of end-users and support the on-boarding and validation of a wide range of use cases. They make use of existing state-of-the-art 5G platforms and also extend coverage by deploying new RAN sites.

The connectivity platforms described in this document include the Luxembourg Facility of SES which focuses on satellite backhauling solutions, the Norway Facility, a multi-vendor 5G facility that supports both 5G-NSA and 5G-SA, the 5Groningen Facility of TNO, the 5G Smart Production Lab of AAU, the IoT XG test Platform of TCELL, and the Connectivity Platform of DNET in Serbia. A table, summarizing all the technologies/capabilities provided by the different platforms, is presented below.

Facility	Technology
Luxembourg Facility of SES and LIST	• LoRa IoT devices • (multi-connectivity) Smart IoT Gateway • Satellite Backhaul • SatCore based on a standard 3GPP Core Network
Norway Facility of TNOR	• 5G devices • Telenor's R&I 5G SA Network • Telenor's 5G NSA commercial Network • 5G Non-Public Networks NPN's
5Groningen Facility of TNO	• 4G/5G devices • 4G/5G private network • Non-Stand Alone or Stand-Alone 3GPP core network
5G Smart Production Lab of AAU	• LoRaWAN • Wi-Fi 6/Industrial Wi-Fi Networks • MuLTEfire Network • 4G/5G (NSA and SA) Networks • Multi-access Gateway • Starlink User Terminal
IoT XG Platform of TCELL	• NB-IoT devices • eMTC devices • 4G/5G devices • 4G/5G networks
Connectivity Platform of DNET	• LoRaWAN • GSM/4G devices • LoRa IoT devices • LoRaWAN IoT Gateway

Table 3: Technologies/capabilities provided by the different platform of the COMMECT project

Finally, we can mention that this deliverable provides the foundation for the COMMECT architecture, as outlined in *Task 1.3 - COMMECT Architecture Definition* of Work Package 1. It will also serve as a crucial reference point for the implementation and testing of the Living Labs in Work Package 4 and Work Package 5.

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