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Abstract	In this deliverable, the solutions developed for the two pilot sites within the Aquaculture vertical are described. The deliverable includes a description of the user application and the network architecture that are going to be deployed, in addition to the testing and verification tools to be used during the evaluation. This deliverable is an updated version of D5.2.
Keywords	5G, 5G-HEART, aquaculture, trials, validation

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DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc.

EXECUTIVE SUMMARY

This deliverable describes the second version of the Aquaculture trial solutions and the trial testing and verification methodologies that are used for the two pilots during Phase 2, being an updated version of D5.2 “Initial Solution and Verification of Aquaculture Use Case Trials”.

The work for the preparation of the Aquaculture trials is split in five different scenarios. These are described here:

- A1S1: Sensory Data Monitoring (Athens, Oslo)
- A1S2: Camera Data Monitoring (Athens, Oslo)
- A1S3: Automation and actuation functionalities (Athens)
- A1S4: Edge and Cloud-based computing (Oslo)
- A1S5: Cage to cage – on site communication (Oslo)

Two pilot sites (Greece, Norway) are prepared for this purpose, each one implementing a subset of the aforementioned scenarios. The Greek pilot aims to validate the application of 5G technologies on three different scenarios, A1S1, A1S2, and A1S3. This is split into three phases planned in the context of the 5G-HEART project where an incremental deployment and testing of the equipment and the underlying 5G infrastructure is taking place to prepare the final trial setup in different stages. During Phase 1, initial deployment of the equipment has been done and is thoroughly tested collecting useful metrics. In particular, cameras and sensors have been installed, covering scenarios A1S1 and A1S2 for this first phase of implementation. During phase 2, A1S3 has initially been deployed in a laboratory environment and will be deployed to the aquaculture site environment after a further testing period. Additionally, more cameras and sensors have been deployed and tested with the existing infrastructure, for stressing the network even more, while moving towards the integration with the network architecture.

The Norwegian pilot aims to validate the application of 5G technologies on scenarios A1S1, A1S2 that were described above, as well as A1S4 and A1S5. The network infrastructure and the user application have been developed separately. The actual installations and on-boarding have been done in Phase 2. The software and hardware components have been prepared in Phase 1 to be ready for deployment. During the current phase, Phase 2, the actual installations have been done for scenarios A1S1 and A1S2, while scenario A1S4 has been tested in the laboratory and plans are in place for it to be moved to the aquaculture site.

This deliverable also describes the required 5G infrastructure to assist in the development of validation trials and provide suitable solutions for the described use cases, based on the network architecture described in D2.3 [1]. In the case of the Greek site, the network solution is based in an end-to-end architecture, since the data should be collected and transmitted reliably. The Non-standalone (NSA) version of deployment has been adopted, using both Long Term Evolution (LTE) and 5G wireless systems. The Radio Access Network (RAN) will collect the data from the equipment on site, through the baseband node. RAN connectivity in the site facility is LTE based. However, the appropriate software will be installed to operate the 3GPP wireless system including LTE (up to 3GPP Rel.14) and 5G (Rel. 15 and upwards). The Core Network (CN) will follow the RAN. A 5G EPC-in-a-box is proposed as a core network, which is a virtualized solution for CN, taking advantage of enabling multiple Virtual Network Functions (VNFs) on a single server. For the case of the Norway site, the solution is also based in an end-to-end architecture, and its deployment has been done in two phases. During Phase 1 the implementation of the NSA (Non-standalone) has been completed during the current phase, Phase 2, while deployment of the Standalone (SA) solution has started during Phase 2. The 5G-VINNI RAN uses 2.1 GHz (Band 1) for the 4G anchor, and both, 3.6 GHz (Band n78) and 26 GHz (Band n257) for the 5G New Radio (5G NR).

With regard to testing and verification, both pilot sites will use different tools to conduct the experiments. In the case of the Greek pilot, a Key Performance Indicator (KPI) validation platform, as well as an Analytics engine are going to be used to collect metrics from the installed equipment and to analyse the data to provide detailed results. Metrics are currently being collected and analysed providing initial results. These are based and built upon the work done in WP2 taking into account the analysis and definition of the user requirements and network KPIs respectively in D2.1 [2] and D2.2 [3]. In the case of the Norwegian pilot, the 5G-VINNI platform provides its own monitoring and testing infrastructure which is being used for collecting and analysing initial metrics during Phase 2. The monitoring and testing tools as well as the results obtained during Phase 2 are documented in this deliverable.

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ABBREVIATIONS

Acronym	Term
3GPP	3rd Generation Partnership Project
4G	4th Generation wireless systems
4K	3,980x2160 pixel resolution
5G	5th Generation wireless systems
5GNR	5G New Radio
5G-HEART	5G HEalth AquacultuRe and Transport validation trials
API	Application Programming Interface
APN	Access Point Name
BBU	Baseband Unit
CN	Core Network
CoMP	Coordinated Multipoint
CPE	Customer Premises Equipment
CPU	Central Processing Unit
DL	Downlink
DOF	Degrees Of Freedom
E2E	End-to-End
ECC	Error Correction Code
EIRP	Effective Isotropic Radiated Power
eMBB	Enhanced Mobile Broadband
FCR	Feed Conversion Ratio
FDD	Frequency Division Duplex
FPS	Frames Per Second
FOV	Field Of View
gNodeB / gNB	Gigabit Node B (5G)
GPU	Graphics Processing Unit
HD	High-Definition
HSS	Home Subscriber Server
ICMP	Internet Control Message Protocol
IR	Infrared Range
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
KMVaP	KPI Management and Validation Platform
KPI	Key Performance Indicator
KVM	Kernel-based Virtual Machine

LTE	Long-Term Evolution
MaaS	Monitoring-as-a-Service
MIMO	Multiple-Input Multiple-Output
ML	Macine Learning
mMTC	massive Machine Type Communications
MQTT	Message Queuing Telemetry Transport
MU-MIMO	Multiple-User Multiple-Input and Multiple-Output
NE	Network Element
NFV	Network Function Virtualisation
NID	Network Interface Device
NR	New Radio
NS	Network Slice
NSA	Non-Stand-Alone
NSD	New Service Development
NTP	Network Time Protocol
NVMe	Non-Volatile Memory
ONVIF	Open Network Video Interface Forum
OVS-DPDK	Open vSwitch Data Plane Development Kit
OWAMP	One-way Active Measurement Protocol
PCIe	Peripheral Component Interconnect Express
PCRF	Policy and Charging Rules Function
P-GW	Packet Data Network Gateway
PoE	Power-over-Ethernet
QoS	Quality of Service
RAN	Radio Access Network
RMS	Root Mean Square
RoIP	Radio over Internet Protocol
RTP	Real-time Transport Protocol
RTSP	Real Time Streaming Protocol
RTT	Round Trip Time
SA	Stand-Alone
SAT	Service Activation Testing
SATA	Serial Advanced Technology Attachment
SFP	Small Form-facor Pluggable
S-GW	Serving Gateway
SSD	Solid-State Drive
SW	Software

TaaS	Testing-as-a-Service
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDS	Total Dissolved Solids
TLS	Transport Layer Security
TWAMP	Two-Way Active Measurement Protocol
UC	Use Case
UDIMM	Unbuffered Dual Inline Memory Module
UDP	User Datagram Protocol
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communications
vCPE	Virtual Customer Premises Equipment
vEPC	virtual Evolved Packet Core
VM	Virtual Machine
VMM	Virtual Machine Monitor
VNF	Virtual Network Function
VR	Virtual Reality

1 INTRODUCTION

Two pilots are being deployed during the lifetime of the project, one in Greece and one in Norway, covering different requirements that exist in two completely different environments. The scenarios that are going to be executed are listed below:

- A1S1: Sensory Data Monitoring (Athens, Oslo)
- A1S2: Camera Data Monitoring (Athens, Oslo)
- A1S3: Automation and actuation functionalities (Athens)
- A1S4: Edge and Cloud-based computing (Oslo)
- A1S5: Cage to cage – on site communication (Oslo)

The two pilots have been developed, each with its selected scenarios, at different levels because of COVID-19 effects as reported in detail in the next sections. The design of the solutions has been provided covering both network and software/hardware related aspects, while the installations and verification are continuously on-going in order to be completed.

In this deliverable, the current setup of the Aquaculture trials for both the user application and the network architecture is described for all the scenarios, as planned during the second phase of the trials. Additionally, details about the testing and verification process are also provided, giving an overview of the Key Performance Indicators (KPIs) that are being studied during the duration of the whole project and the tools used.

2 A1S1 SENSORY DATA MONITORING

2.1 Description and motivation

The description of the use case scenario A1S1 can be found from Section 2.1 of D5.2 [1].

2.2 Proposed setup

2.2.1 Network architecture

2.2.1.1 Greek pilot

For the Greek pilot, 5G-EVE testbed will be used. More specifically, OTE will manage the network architecture that is going to be used during the trials, while ERICSSON will be providing the network equipment. The main architecture is described on D5.2 Section 2.2.1.1 Greek pilot [1] and on D2.3 section 4 5G-EVE [2] (Figure 1).

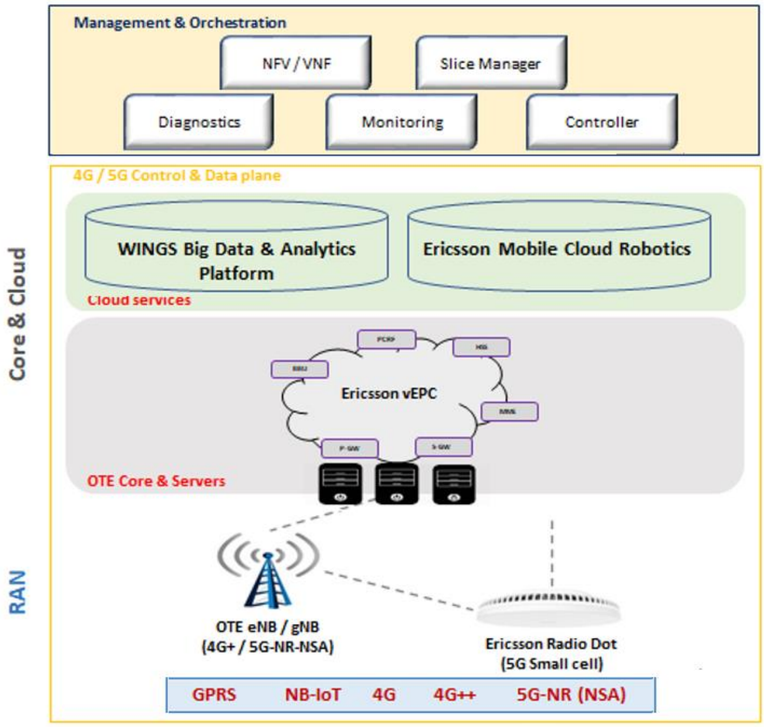


Figure 1: High-level network architecture of 5G-EVE testbed

During Phase 2, the testbed was extended and the transport network was finalised. User and Control Plane were integrated and connected to the virtual Evolved Packet Core (vEPC) through the packet optical transport network.

As NSA solution has been followed, LTE Control Plane is used for the connectivity with Core to support signalling between Radio and Core nodes. NR Control Plane is used for the signalling between eNodeB and gNodeB installed at MEGARA site. User Planes from both LTE and NR are contributing on the traffic sessions served by the Radio Nodes.

In our implementation one /29 subnet has been used for Control Plane and a different /29 subnet has been used for the User Plane. Each subnet has its own VLAN. Each subnet provides 1 IP for LTE and 1 IP for NR. The CP/UP separation is done through parameterization in the eNodeB and gNodeB.

At the same time, the end user equipment was installed, as it is presented in Figure 2. The WINGS smart gateway was connected to the Radio Access Network (RAN) which was integrated on SKIRONIS premises, while a camera, provided by ICOM, was connected to the testbed through a fixed connectivity with a server.

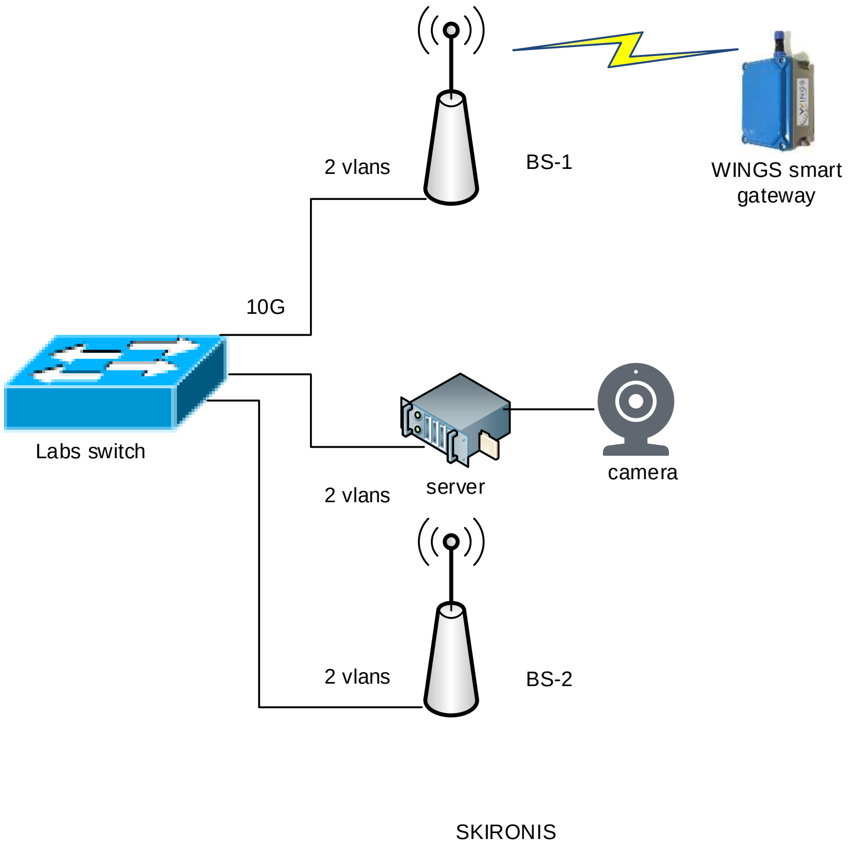


Figure 2: End user equipment installed in SKIRONIS premises.

RAN components:

The RAN network consists of the RAN HW equipment necessary for enhanced indoor coverage and 4G+ RAN software optimized to match the use case requirements in terms of throughput and latency. Indoor cellular coverage is provided by deploying Ericsson's indoor Radio Dot System (RDS) solution. This is a high performance distributed active radio antenna system based on a centralized RAN architecture. A simplified diagram is shown in Figure 3.

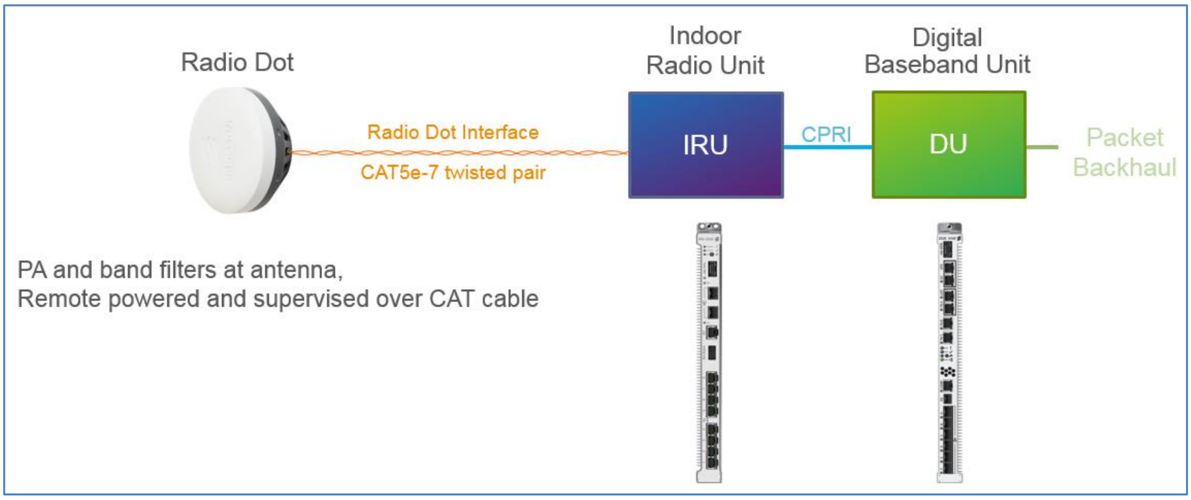


Figure 3: RDS architecture

The Ericsson RDS consists of 3 key components:

• Radio Dot (RD) with Active Antenna: The radio dot contains the power amplifier and filters for the frequency band(s) selection. The frequency band used is the 2600 MHz (B7 band) with 20 MHz of operational bandwidth. The radio dot is powered from the Indoor Radio Unit (IRU) over up to 200 m LAN cable.

• Indoor Radio Unit (IRU): The IRU provides power and control for the RDs. It generates the RD interface on 8x RJ45 ports and connects to the active antenna over standard enterprise LAN cables.

• Baseband 6630: The baseband unit is connected to the IRUs over the CPRI interface. The baseband runs the 4G+ SW functionality and provides the transport interface with the equipment hosting the virtual EPC. Currently the installed baseband is operating 4G+ only functionality however Ericsson will upgrade the access technology such as to support 5G NR technology as well. The baseband HW along with the interfaces front panel is shown in Figure 4.

Figure 4: Baseband 6630 front panel

More detailed information on Ericsson's RDS unit can be found at D2.1 document.

• Operation Frequency Bands

The frequency bands used for the 4G+ Ericsson RAN solution are the following:

• The B7 which is, FDD 2600 MHz with 20 MHz spectrum deployment, based on the selection criterion to minimize interference and overlapping coverage with the commercial OTE/COSMOTE MBB network.

• B42 (TDD, 3500 MHz) is used for deployment of the 5G-NR in order to provide 5G access at the Greek site facility.

The currently available LTE+ system can support high DL throughput of up to 200 Mbps using one LTE 20 MHz carrier (B7:2600 MHz) using higher order modulation 256QAM and up to 75 Mbps in UL using 64 QAM. This is the first phase of RAN SW/HW deployment which is compliant to LTE Advanced Pro technology included up to 3GPP R14 specifications. However, the 4G+ system architecture is also in line with the radio network architecture of 5G. It can coexist with pure 5G NR radio by including additional RDs optimized for 5G NR as it is depicted in the figure.

Besides connectivity throughput, of paramount importance for a high-performance network connecting mobile robotics to the cloud is latency and jitter. For example, an UL speed of 60 Mbps or higher, maximum acceptable jitter of less than 5 ms, no data buffering and end-to-end latency of less than 80-100 msec (including transmission and processing time) is required to ensure seamless and safe operation.

Ericsson's proposed SW solution meets those requirements by deploying advanced network functionality such as the Instant Uplink Access (IUA). Specifically, IUA eliminates the need for explicit scheduling request and individual scheduling grants. Through pre-allocation of radio resources IUA can reduce the average radio Round Trip Time (RTT) latency (i.e., UL and DL) to 9 ms, which is a significant improvement compared to traditional LTE R13 RTT latency of 16 ms.

Additionally, during Phase 2 the slicing mechanism was configured, offering different slices by adopting Access Point Name (APN) differentiation slicing mechanism. The use of APN offers Core Network (CN) slicing by separating different APNs on different Packet Data Network Gateways (PGWs). There are two different ways to support APN slicing: the static selection based on APN configuration in Home Subscriber Server (HSS) and the dynamic selection based on mobility policies configured in Policy and Charging Rules Function (PCRF). In the Enterprise Core setup which is in use to support the 5G HEART project, a static selection is supported.

2.2.1.2 Norwegian pilot

The 5G-VINNI network in Norway – and in particular the installation at Gjerdinga fish farm site – will be used for the technical evaluation. Refer to D5.2 [1], Section 2.2.1.2 Network architecture/Norwegian pilot or to D2.3 [2] Chapter 2 5G-VINNI for details. The implementation used is an enhanced Mobile Broadband (eMBB) slice as shown in Figure 18 in [6].

2.2.2 User application architecture

2.2.2.1 Greek pilot

The user application architecture is the same as the one described in D5.2 section 2.2.2.1 [1]. Additionally, a user Dashboard is used to monitor and manage the aquaculture system. The user is able to access information about the aquaculture site's status, monitoring the current situation, from a water quality and production perspective as well as a behavioural and infrastructure one. Additionally, maintenance, production and husbandry activities are organised and coordinated through the Dashboard.

The core of the system is developed, maintained and deployed around the data storage and distribution components as a software platform system hosting all capabilities and services offered to the operator. These include the data broker aggregating all incoming data and publishing it to any application listening to it and to the database where all data is managed and stored.

The overall architecture of the aquaculture dashboard solution is shown in Figure 5.

As shown in this figure, the main components of the platform include:

- A user Dashboard used to monitor and manage the aquaculture system. The user is able to access information about the aquaculture site's status, monitoring the current situation, from a water quality and production perspective as well as a behavioural and infrastructure one. Additionally, maintenance, production and husbandry activities are organized and coordinated through the Dashboard.
- The core of the system is developed, maintained and deployed around the data storage and distribution components as a software platform system hosting all capabilities and services offered to the operator. These include the data broker aggregating all incoming data and publishing it to any applications listening to it and the database where all data is managed and stored.
- Advanced Analytics functionalities which is responsible to analyse various functionalities of the aquaculture environment
- The Decision Support System, which depending on the results provided by advanced algorithms it, takes a decision on what action the system should take. The dashboard provides a rich

interface to interact with the data management system that support a number of systems regarding optimal feeding, production planning, disease mitigation, environmental footprint, etc.

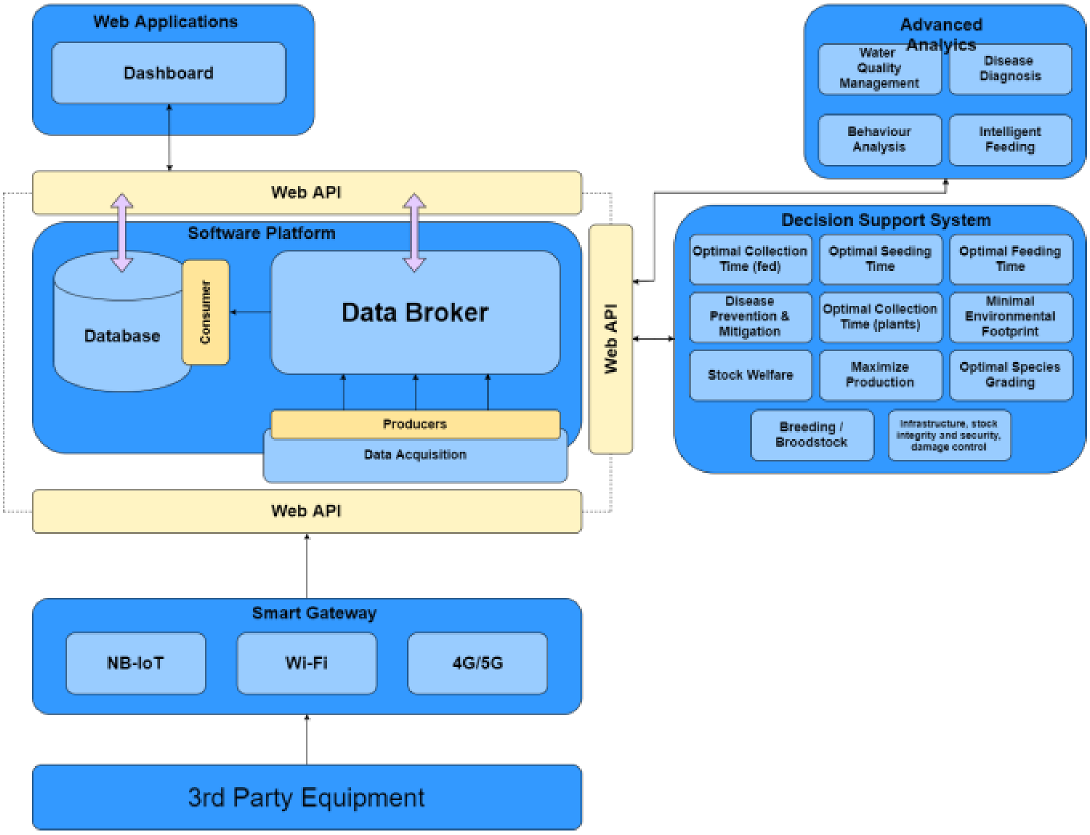


Figure 5: Dashboard architecture.

The dashboard has been developed to provide a series of monitoring and management functionalities, as seen in Figure 6.

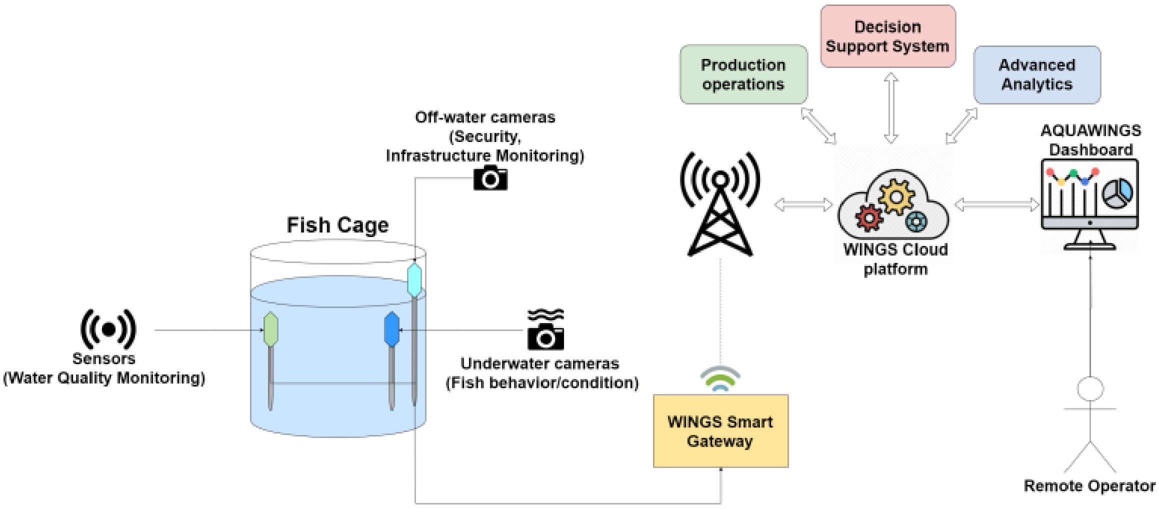


Figure 6: A schema of the different modules of the dashboard.

The solution is composed of the additional following modules:

- Monitoring of the production such as stock density, FCR, stock size functions which are visualised on the information page.
- Environmental monitoring by utilizing a series of sensors installed in the gateway to monitor the sea water quality
- Behavior monitoring where the user can select one of the installed cameras to live stream its output.
- User data input which are data that concern fish production and currently it is done manually while in the future it will be done automatically
- The Smart Gateway that is equipped with sensors and cameras to monitor and detect the environment. The gateway retrieves data from the sensors and transmits them over the available network. It is equipped also with a camera that transmits online video to the 5G network.

The Web application or Dashboard of the Smart Aquaculture solution is the main access point for the end user to use the software platform. The User Interface (UI) environment comprises multiple components, each of them implementing a view element responsible for a unique task triggered by a specific user interaction. Multiple components form a shared module.

Each component instantiates its relevant UI elements and interacts asynchronously with core Angular framework dedicated services, mainly for data exchange purposes with internal, e.g., other services, or external sources, i.e., REpresentational State Transfer (REST) service calls, web socket incoming data, file downloading. After any of the abovementioned asynchronous interactions, the data retrieved are injected into relative UI elements using asynchronous pipes or trigger specific actions, e.g., activating other components from default or specific module hierarchy.

2.2.2.2 Norwegian Pilot

The User architecture for A1S1 is the same as presented in D5.2 Section 2.2.2.2 User application architecture/Norwegian pilot [1].

2.2.3 Hardware components

2.2.3.1 Greek pilot

The hardware components for the A1S1 scenario are the same as the ones presented in D5.2 section 2.2.3.1 [1].

2.2.3.2 Norwegian pilot

Hardware components for A1S1 are the same as presented in D5.2 Section 2.2.3.2 Hardware components/Norwegian pilot [1], except that it is decided to exclude the Fiber Cabinet from the setup as it is not needed.

2.2.4 Software components

2.2.4.1 Greek pilot

The software components are the same as the ones described in D5.2 Section 2.2.4.1 Software components/Greek pilot [1].

2.2.4.2 Norwegian pilot

The software components required for A1S1 are the same as the ones described in D5.2 section 2.2.4.2 [1].

2.3 Testing and Verification

The testing and verification are common for all the scenarios of the aquaculture use case and thus presented in a separate section later in the document (Section 7) providing details on the analysis of the methodology, key performance indicators, testing tools and initial results for both pilots, the Greek and the Norwegian pilot in Sections 7.1.1 and 7.1.2, respectively.

2.4 Next step plans

Greek Pilot

At phase 2 most of the work involved the installation of the smart gateway with its sensors in the Skironis aquaculture cages. The testing involved monitoring of the water quality and communication with the 4G network at Skironis and with the 5G network in the lab. The dashboard is accepting production data of fish and then the dashboard it processes them in order to output data such as the fish weight and food conversion ratio (FCR).

At phase 3, the experiments will be performed by using the 5G NR whose installation is currently under finalization in the area.

Norwegian Pilot

During phase 2, the main work at the Norwegian aquaculture site has been to install and implement the application edge at the feed barge and installing the 5G-VINNI RAN node. By the end of 2020 a control room was installed on the feeding barge, fiber infrastructure was installed from the barge and to the cages and sensors and cameras were installed in all cages. As the network was still not up and running it was not possible to carry out any test yet. In May 2021 the site was harvested and therefore all installed equipment was uninstalled. Next planned production at Gjerdinga is April 2022. Equipment is planned to be reinstalled again then.

The 5G-VINNI gNB at Gjerdinga will be configured and tested before end of 2021. Following that, network KPI tests will be performed as well as coverage investigations for both frequency ranges; 3.6 GHz and 26 GHz until the aquaculture feed barge is operational again, expected in April 2022. Also, the current onboarding setup to 5G-VINNI is based on a shared eMBB slice in Non-Standalone (NSA) mode. Upgrades planned are to install an isolated Ultra-Reliable Low Latency Communications (URLLC) slice. We will also consider migrating the use case to a Standalone (SA) setup. SEALAB will reinstall equipment on feeding barge and in the cages again when a new production starts on Gjerdinga, estimated to be in April 2022.

3 A1S2 CAMERA DATA MONITORING

3.1 Description and motivation

This section describes the work performed for the second scenario, the A1S2, which includes the installation of the camera in the smart gateway. The purpose of the camera is to monitor the sea and fish and provides an online streaming of the environment.

3.2 Proposed setup

3.2.1 Network architecture

Please refer to section 2.2.1.2 for the network architecture setup.

3.2.2 User application architecture

3.2.2.1 Greek pilot

The user architecture is the same as the one presented in D5.2 section 3.2.2.1 User application architecture/Greek pilot [1].

3.2.2.2 Norwegian pilot

The user architecture for A1S2 is the same as presented in D5.2 section 3.2.2.2 User application architecture/Norwegian pilot [1].

3.2.3 Hardware components

3.2.3.1 Greek pilot

The developed monitoring solution for security surveillance of the infrastructure is using a 360° surveillance camera to provide infrastructure visibility and support the early detection of physical intrusions. The camera used allows the dynamic update of the focus angle, called as field of view (FOV), as well as the visualisation of multiple streams at different resolutions. In the implemented scenario, lower quality video can be visualised when changing the FOV for minimizing the delay, while when the FOV is stabilised the quality of the video can be optimised by changing the high resolution stream. The 360^0 on-surface camera for infrastructure monitoring with VR/360^0 video delivery has been installed on the aquaculture facility to provide surveillance of the aquaculture site connected via Ethernet to ICOM's server. The camera specifications are shown below:

- Frame rate: 25 frames per second (FPS)
- Ingress and impact protection standards: IP67, IK10
- Power supply: Power over Ethernet (PoE) connectivity
- Interoperability: ONVIF (Open Network Video Interface Forum) compliant
- Infrared Range (IR) Distance: up to 10m (33ft)
- Streaming capability: Outputs 3 Streams
- Video codec: H.265/H.264/MJPEG

For the purpose of capturing the camera streams and applying video transformations and analytics, a server with an NVIDIA graphics card with with CUDA technology has been used. The specification of the server can be found below [3].

Dell Workstation Tower Precision 3650:

- CPU: Intel Core i9-11900, 16 MB Cache, 8 Core, 2.5 GHz to 5.2 GHz
- RAM: 32GB (2x16GB) DDR4 unbuffered dual inline memory module (UDIMM) non-Error Correction Code (ECC) Memory
- Hard Drive: 512GB Peripheral Component Interconnect Express(PCIe) Non-Volatile Memory (NVMe) Class 40 M.2 Solid State Disk (SSD)
- Additional Hard Drive: 1TB 7200rpm Serial Advanced Technology Attachment (SATA) 3.5" hard disk drive (HDD)
- Graphic Card: Nvidia Quadro RTX 4000, 8GB, 3DP, VirtualLink

The Nvidia Quadro RTX 4000 is powered by the NVIDIA Turing™ architecture and the NVIDIA RTX™ platform and is designed for advanced visual computing workflows such as ray tracing, deep learning, and advanced shading. The ICOM server uses its capabilities for Graphics Processing Unit (GPU) accelerated video decoding/encoding and filter applying. Its specifications can be found in the image below:

	RTX 4000
CUDA Parallel-Processing Cores	2,304
NVIDIA Tensor Cores	288
NVIDIA RT Cores	36
GPU Memory	8 GB GDDR6
RTX-OPS	43T
Rays Cast	6 Giga Rays/Sec
FP32 Performance	7.1 TFLOPS
Max Power Consumption	160 W
Graphics Bus	PCI Express 3.0 x 16
Form Factor	4.4" (H) x 9.5" (L) Single Slot
VR Ready	Yes

Figure 7: NVIDIA RTX4000 specifications.

Regarding the underwater camera a new stereoscope camera is used during Phase 2 as the one shown in the following figure (Figure 8: Stereo-scope underwater camera used in Skironis region in Greece.

Figure 8: Stereo-scope underwater camera used in Skironis region in Greece.

This camera is used in Phase 2 that provides full customizable field of view (FOV). Several issues existed with its installation in the cage and the detection of fish and cage and also with its maintenance had issues with water insulation and maintenance. The installation of the camera in the cage is shown in the following Figure 9: Installation means of the stereo-scope camera in Skironis.

Figure 9: Installation means of the stereo-scope camera in Skironis

3.2.3.2 Norwegian pilot

Hardware components for A1S2 are the same as presented in D5.2 Section 3.2.3.2 Hardware components/Norwegian pilot [1].

3.2.4 Software components

3.2.4.1 Greek pilot

Software related to the functionality of the 360^0 on-surface camera has been installed for capturing and processing the two Real Time Streaming Protocol (RTSP) streams with H264 encoding (a high resolution stream of 4000x3000 pixels and a low resolution one of 704x576) provided by the camera. The two streams are picked by the intermediary server with the use of OpenCV [4] library, where each frame is decoded and processed (cropping, undistortion etc.). After the processing is completed, the server outputs the frames with the use of two FFMPEG [5] pipelines that re-encode in H264 and output an RTP stream each. Finally, ICOM’s streaming server is used to manage the Real-time Transmit Protocol (RTP) streams with the RTSP, making them accessible to multiple users.

Software for the new camera was incorporated in the application and the view of fish was better than the previously installed camera. Installation difficulties existed for this camera and still there is a task to find the best placement of this camera.

3.2.4.2 Norwegian pilot

Software components for A1S2 are the same as presented in D5.2 Section 3.2.4.2 Software components/Norwegian pilot [1].

3.3 Testing and Verification

The testing and verification are common for all the scenarios of the aquaculture use case and thus presented in a separate section later in the document (Section 7) providing details on the analysis of the methodology, key performance indicators, testing tools and initial results for both pilots, the Greek and the Norwegian pilot in Sections 7.1.1 and 7.1.2, respectively.

3.4 Next step plans

Greek Pilot

For phase 2 most of the work involved the installation of the camera in the cage and incorporation of the video software in the gateway for live streaming the fish environment in the cage. The proper place of the camera in the cage was tested at different places in the cage in order for the gateway to produce most of the useful results and also to be easily accessible by the personnel for cleaning and configuration purposes. The camera was tested with 4G network in the area.

For phase 3 the optimal place of the camera in the cage will have to be determined. The camera and the video streaming will be tested with 5G NR base stations as this work is finalizing. The user software will be optimized to include the automatic input of production data to the dashboard.

Also, software for the inclusion of the underwater camera will be updated to examine and detect fish quality and food that gets lost.

At this phase a surveillance camera will be installed that will be used to monitor the region around the whole area. The network will be tested under heavy uplink bit rate since there will be data from the sensors, data from the underwater camera and data from the surveillance camera. KPIs for throughput will be tested. Therefore slices for eMBB will have to be setup in the network to verify the high throughput needed for the cameras.

Norwegian Pilot

During phase 2, the main work at the Norwegian aquaculture site has been to install and implement the application edge at the feed barge and installing the 5G-VINNI RAN node. By the end of 2020 a control room was installed on the feeding barge, fiber infrastructure was installed from the barge and to the cages and sensors and cameras were installed in all cages. As the network was still not up and running it was not possible to carry out any test yet. In May 2021 the site was harvested and therefore all installed equipment was uninstalled. Next planned production at Gjerdinga is April 2022. Equipment is planned to be reinstalled again then.

4 A1S3 AUTOMATION AND ACTUATION FUNCTIONALITIES

4.1 Description and motivation

This scenario involves the incorporation of a drone to be placed in the fish cage for continuously monitoring the quality of the cage (ex. If the net is broken, if an intruder to the cage is approaching, etc. Currently most of the aquaculture systems are using human persons to inspect the nets at certain periods, not continuously which is something that requires extra staff effort. With the use of the drone the operational costs can be lowered and cage condition can be provided online continuously. Therefore the use of the drone in fish cages can automate the otherwise tedious human involvement tasks.

4.2 Proposed setup

4.2.1 Network architecture

The network architecture that will be used was described in details in D5.2 Section 2.2.1.1 [1].

4.2.2 User application architecture

The application is the one that is described in D5.2 Section 4.2.2 [1].

4.2.3 Hardware components

At phase 2 the BlueROV2 drone was first tested in the lab for checking any performance issue. The lab tests that were performed in small water cages went relatively well since some water leakage affected the drone performance. The BlueROV2 is an affordable, high-performance underwater Remotely Operated Vehicle (ROV) manufactured by Blue Robotics Inc. It comes with an eight-thruster configuration with 6 Degrees of Freedom (DOF) that offer high manoeuvrability and high-performance navigation under harsh underwater conditions. It has open-source software, a modular frame design and a large number of accessories that increase flexibility and expandability for the task of sea aquaculture monitoring. It includes two high-end LED lights, a full High-Definition (HD) camera, comes with a depth rating and tethering cable of 100m and its own fathom spool. The drone is shown in Figure 10.

Figure 10: Underwater drone used in Skironis fish cage in Greece

4.2.4 Software components

The application architecture for monitoring is the same as the one presented in deliverable D5.2 at Section 4.2.4 [1]. The solution provides a direct connection between the user and the underwater system used to monitoring fish and water quality. The platform has been advanced with a decision support system for the farmer in terms of learning fish health and productivity. Experiments are performed every day in order to monitor fish production and optimal feeding. Currently data regarding the fish weight and feeding weight are collected from the farmer and injected in the system in order to predict the production indices biomass and Feed Conversion Ratio (FCR).

4.3 Testing and Verification

The testing and verification are common for all the scenarios of the aquaculture use case and thus presented in a separate section later in the document (Section 7) providing details on the analysis of the methodology, key performance indicators, testing tools and initial results for both pilots, the Greek and the Norwegian pilot in Sections 7.1.1 and 7.1.2, respectively.

4.4 Next step plans

At phase 2 the drone was operated in a small water cage in a lab area. Some issues existed with water leakage in the drone.

For phase 3 the drone will be placed in Skironis cages to detect the quality of the cage. For phase 3 the platform will be updated so that data from the farmer will be collected in an automatic way for further processing. Also, graphs are planned to be produced regarding the production indices FCR and fish weight. The software will be updated to include functionalities of the drone so that the whole system will be working in an automatic manner displaying production parameters and a view of the cage. A uRLLC slice will be setup for testing the latency KPI needed for the drone and the surveillance camera.

The roadmap for phase 3 is shown in the following table:

Table 1: Phase 3 roadmap.

Phase 3 roadmap	
Period	*Work description*
Quarter I	Test the drone underwater in Skironis area
Quarter II	Incorporate the software for the management of the drone in the dashboard
Quarter III & IV	Test the drone with 5G NR as the network is finalising now. Setup a uRLLC slice for testing the low latency KPI needed for the drone and the surveillance camera

5 A1S4 EDGE AND CLOUD-BASED COMPUTING

5.1 Description and motivation

There are still many processes in the aquaculture industry that can be automated both for decision support or fully automated decision making, based on input from various data. Monitoring the production generates massive amounts of data to be processed and analysed by the farmer. The lack of good network solutions can be restrictive for these amounts if the data transmitted from the site requires higher bandwidth than what is available. For that reason, edge- and cloud-based processing is needed to get the right data at the right time, for the right purpose. Every cage will represent a unique stream of raw data from sensors and cameras, and will be processed before entering the barge or the cloud. This scenario is implemented to the Norwegian pilot site.

5.2 Proposed setup

5.2.1 Network architecture

In the 5G-VINNI Norway Facility, several Edge designs have been implemented and planned in the architecture. For a full scope and description of those concepts, 5G-VINNI deliverables D1.4 [6] and D2.1 [7] can be consulted.

In the context of this document, it can be mentioned in general that Edge Cloud brings computing and storage closer to the customer. Within 5G-VINNI, the incorporation of Edge platforms demands a deeper assessment on the cost and needs balance. Edge infrastructure brings additional costs that must be considered.

Operator internal drivers are typically related to expanding the network clouds towards the edge to enable distribution of network functions and content for efficient delivery and production of services, including core, RAN and content. Enterprise use case drivers are related to utilizing the mobile network and infrastructure to solve customer needs, e.g., by replacing legacy systems, introducing systems for process automation, and enabling new services. Consumer use case drivers are related to reducing latency and more efficient delivery of consumer services.

For the use cases related to 5G-HEART it is worth to mention two types of edge as described in Figure 11; the device and the access edge.

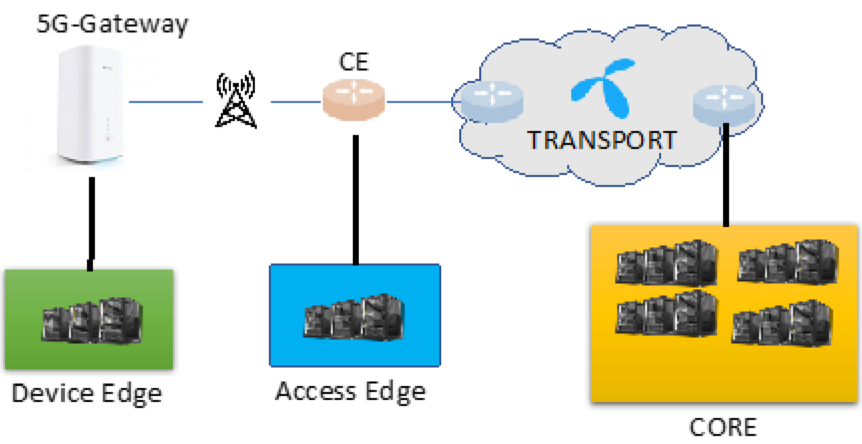


Figure 11: Overall view on Edge Design and types.

The access edge is the one that hosts network functions for serving enterprise use cases. It is located at or close to customer premises. There will be varied implementations adopted for the specific use cases, ranging from small deployments with basic infrastructure such as for low latency applications to larger deployments hosting the complete mobile core network to ensure autonomy and private networks. Enterprise applications might also be hosted in Enterprise Edge Cloud (Figure 12). This type of edge is the one that in principle is considered in the scope of Figure 13 presented in D5.2 Section 2.2.1.2.1 (Core Solution and Slice Design of the 5G-VINNI Norway Facility) [1].

The Device Edge hosts only enterprise applications and no network functions. It is located at customer premises (behind the 5G-Gateway). It is used for tasks such as data analytics and hosting or enterprise applications. In the case of the fish farm, this type of edge is the one that will be implemented at an initial stage. At the moment of writing this document this edge is under construction and the purpose of it is to allocate artificial intelligence algorithms that will process some of the images from the cameras mentioned in previous sections. The objectives with this type of edge are two: First, to have direct information on potential sickness or special circumstances at the fish farm directly at the platform. Second, to avoid to send redundant and unnecessary information via the 5G channel.

The technical details on the implementation of this edge can be found in 5G-VINNI Deliverables D1.4 [6] and D2.1 [7], and a brief overview of the infrastructure to be used in such edge is presented below.

Figure 12: Infrastructure used on the Device edge in the Norway fish farm use case.

The employed hardware is the following:

- 1x 3U Chassis
- 5 x Servers (24c, single CPU, 192GB RAM)
- 1x Z9100 leaf switch (32x100Gb ports)
- 2x GPU NVIDIA capability for the servers
- Openstack Rocky release
- All servers can work as compute nodes
- High availability Openstack with 3 controllers
- CEPH storage solution with SSD disks

5.2.2 User application architecture

User application architecture for A1S4 is the same as presented in D5.2 User application architecture Section 5.2.2 [1].

5.2.3 Hardware components

In addition to the hardware components used in A1S1 and A1S, D5.2 Section 2.2.3.2 Hardware components/Norwegian pilot [1] and an application server (device edge) is installed on the barge. SEALAB is working with Nokia on setting up this server, which will be used as the main on-site processing unit and will host virtual machines for AI applications and video distribution.

The application server specifications are the following:

- Around 196 hyperthreaded vCPUs
- 650-700GB RAM
- 2.7-3TB SSD storage (CEPH)
- 2x25GB network ports in each server. One may be used for infra and the other one for tenant traffic
- 2 GPUs
- Open vSwitch Data Plane Development Kit (OVS-DPDK) with 2 Cores allocated per server (4vCPUs) for Virtual Machine(VM) networking

5.2.4 Software components

Artificial Intelligence

Initially, SEALAB will use the video distribution server to run a pellet detection AI. This uses a simple blob detector to find round objects in a picture. A snippet of that object is then passed to the AI that determines whether the snippet is of a pellet or not. This processing is performed entirely on the CPU, as the GPU communication overhead takes longer than the resulting increase in processing speed. As the content of each blob can be classified independently, our solution to increase throughput is to automatically scale the number of parallel AIs based on the hardware of the system it is running on or a predefined number. This means a high core count setup will be better for this application, as more blobs can be processed in parallel. Real time data will be presented to the operator on a video overlay, providing decision support during feeding.

Video distribution

The software behaviour of this solution is described in section 3.2.4.2 in D5.2 [1].

5.3 Testing and Verification

The testing and verification are common for all the scenarios of the aquaculture use case and thus presented in a separate section later in the document (Section 7) providing details on the analysis of the methodology, key performance indicators, testing tools and initial results for both pilots, the Greek and the Norwegian pilot in Sections 7.1.1 and 7.1.2, respectively.

5.4 Next step plans

The edge rack was moved to a different location after the fish at Gjerdinga was harvested. There is no 5G-network connection at the new site, but the purpose of moving it was to start some testing and preparations for when we can move the rack back to the original test site, Gjerdinga. Pellet detection AI will be run on the 4G-network, and different metrics will be measured to see where the restrictions on the 4G-network are to compare with the 5G-network. The video distribution server is going to be installed alongside the rest of the equipment to allow the proceeding execution of the trials for this scenario.

The edge rack will be moved back to Gjerdinga when a new production of Atlantic Salmon starts there, estimated to be in April 2022.

For the network architecture evolution and setup, please refer to Section 2.3 (A1S1).

6 A1S5 WIRELESS COMUNICATION ON SITE

6.1 Description and motivation

The capacity of the 4G network is too low to support the amount of data required to operate and navigate underwater cameras in real-time, therefore cable networks (fiber optics and ethernet) are being used. Using fiber cables to transfer data between the cages and feeding barge is challenging as these are exposed to breakage and damage. This can lead to downtime on the camera system, which is critical for several daily activities, for example feeding.

By moving the 5G connection point from the centralised feed barge of the site to connection points at each cage, this test will also identify the benefits of 5G technologies in comparison with cabled networks (e.g. fiber optics, ethernet) and wireless networks such as 4G, and Radio over Internet Protocol (RoIP) that are most frequently used today. Bandwidth, latency and coverage will be measured in this test. In Figure 13, the pilot site with the planned installed equipment is presented.

This scenario is implemented to the Norwegian pilot site. The scenario has been separated into two parts, where part 2 will be an experimental scenario. The separation of this scenario is done to ensure that the communication between the 5G-base station and the nearest fiber infrastructure in Rørvik supports the amount of throughput needed.

A1S5 Part 1: One wireless cage

The first part of this scenario will only be based on one cage communicating to the barge over 5G-network. A 5G-gateway will be installed on the cage. The fiber cables will still be present to have a back-up solution for the farmers to keep control of fish welfare and water quality while the tests are being performed. On the wireless cage, the fiber will only go through a separate fiber cabinet to keep the ring structure and secure fiber connection to the other cages. Testing one wireless cage before starting part 2 will reveal potential barriers and results from this scenario will be used to perform part 2.

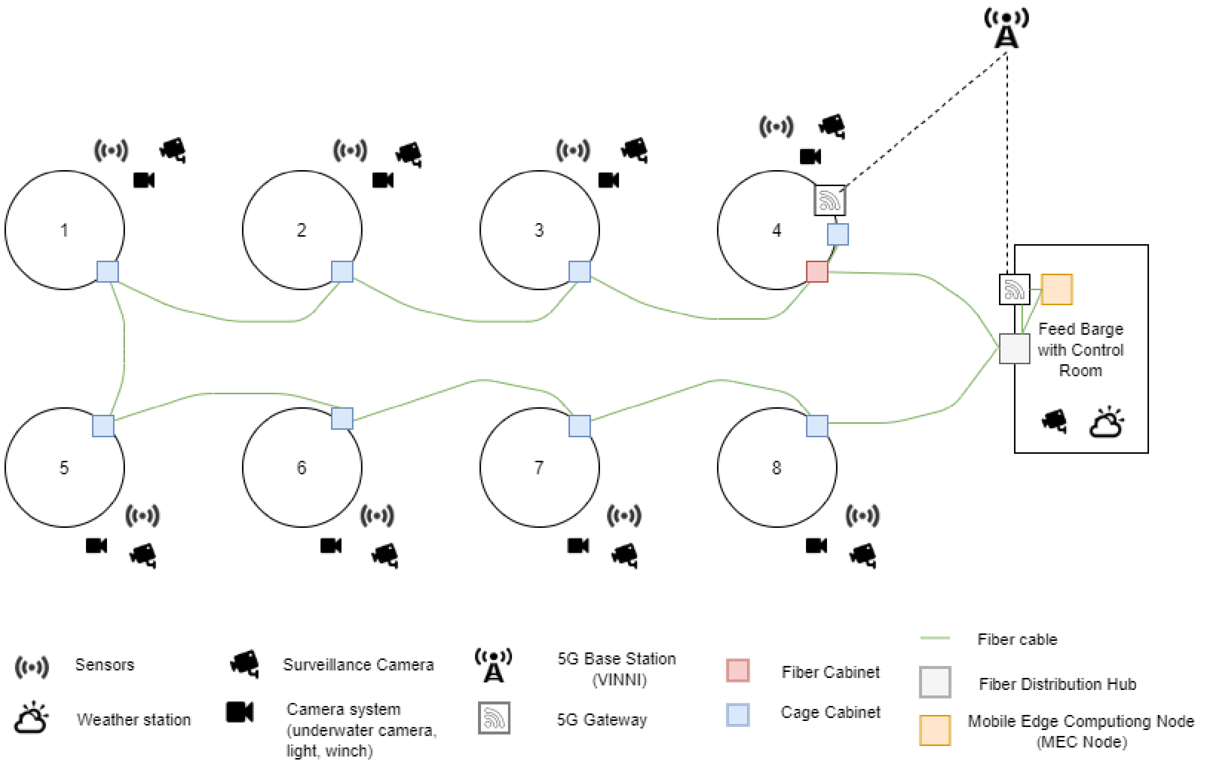


Figure 13: Illustration of the pilot site with the planned installed equipment for A1S5 part 1, where one cage uses wireless communication.

A1S5 Part 2: Wireless communication on site

Part 2 of the scenario relies on results from part 1. Instead of just one cage communicating over 5G-network, the whole site will be wireless. The fiber cables will, like the one cage in part 1, still be present through a separate fiber cabinet but not utilised. Instead, a 5G gateway will be installed on all cages. In addition, this scenario requires a video distribution server at the base station because the data is not sent through the video distribution server node at the barge, and the bandwidth is not sufficient for sending all data from the base station.

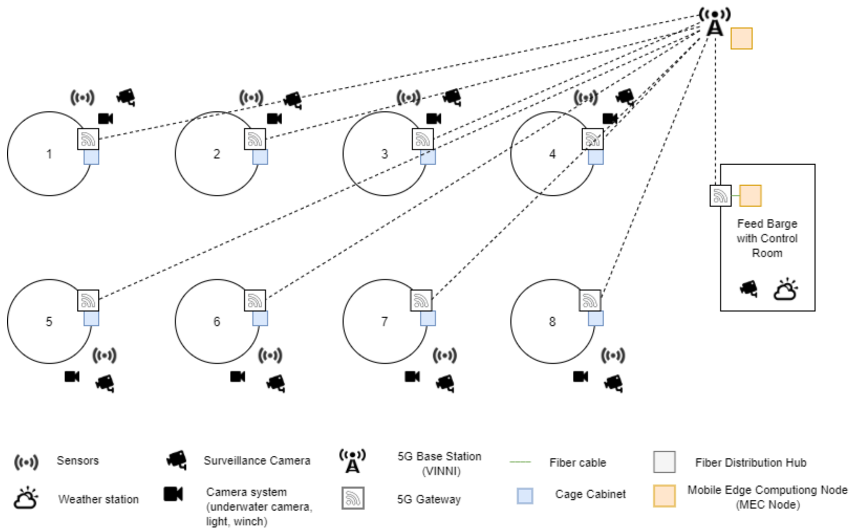


Figure 14: Illustration of the pilot site with the planned installed equipment for A1S5 part 2, where all cages communicate wirelessly.

Figure 14 presents the final target of Part 2. However, the implementation will be split in two phases in order to have a gradual approach that guarantees a successful delivery.

Part 2 - Phase 1: Hybrid Deployment with centralized and decentralized 5G-Customer Service Equipment (CPE) Gateway

The same concepts explained in part 1 apply. However, here two of the cages will be connected to the centralized switch, and information will be transmitted directly to the 5G antenna, as presented in Figure 15.

This hybrid solution will allow initial comparison of the centralised and decentralised from two points of view. First, the performance of the telecommunications solutions in both cases. Second, the experience from the use case point of view and the potential differences in terms of effective solution of fish farm problems.

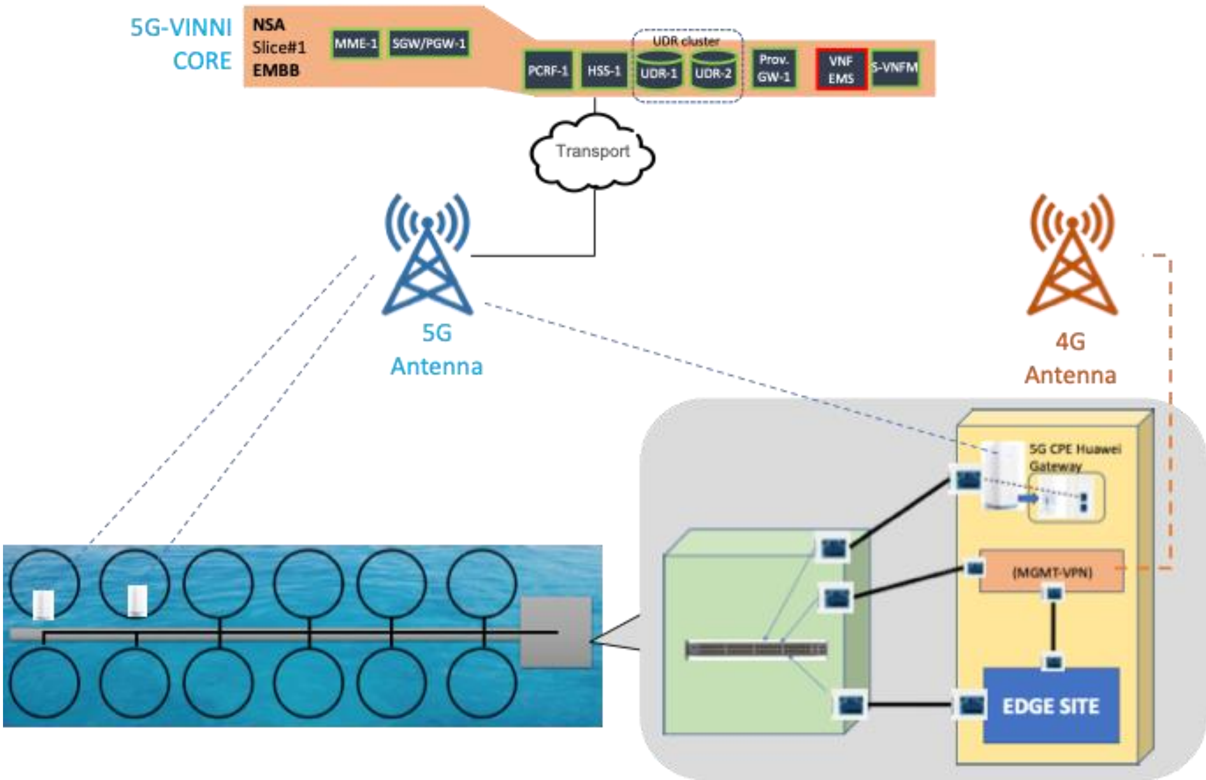


Figure 15. Fish Farm use case. Implementation in Phase 2.

Part 2 - Phase 2: Fully decentralized 5G-CPE Gateway

Finally, this solution plans to get rid of all internal optical fibers in the farm and transmit all the data via the 5G antennas. This phase is planned in a very late stage and dependent on the results observed in Phase 2. The solution is presented in Figure 16.

This solution has in principles two important considerations:

1. The need of several 5G-CPEs. This does not represent a major challenge, but just an important variable to consider.
2. The reduction of the transmission rate of the cameras from 200Mbps to a much lower bandwith How much is still to be analysed, but it is in principle expected a reduction from half to a quarter of the original speed used on Phase 1.

Based on the second point presented, there are very important analyses that need to be taken on the implementation of this use case.

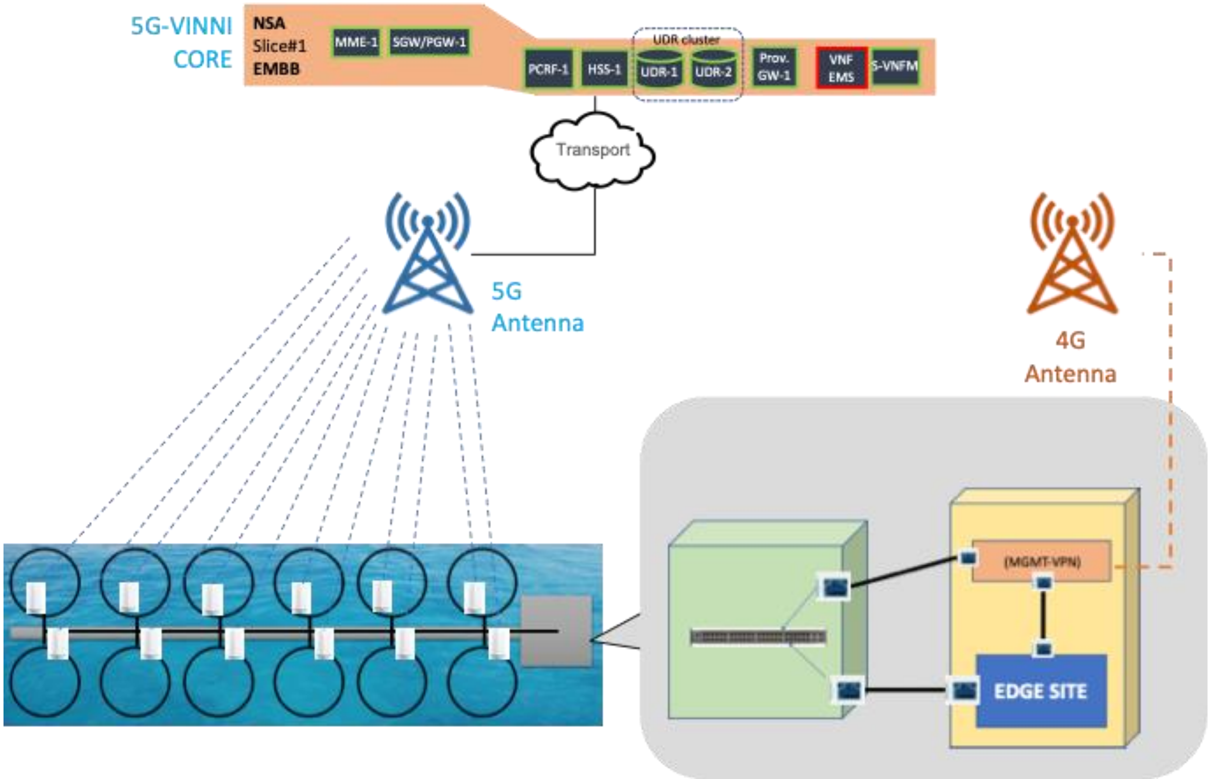


Figure 16: Fish Farm use case. Implementation in Phase 3.

6.2 Proposed setup

6.2.1 Network architecture

The network architecture that will be used was described in details in Section 2.2.1.2.

6.2.2 User application architecture

The user architecture for scenario A1S5 for the Norwegian pilot is shown in Figure 17. This scenario focuses on wireless communication on site. This includes the final setup of the site and communication installations, as well as the integration of the overall solution with the network. During this phase, feedback from the previous phases is evaluated and utilised to generate the final version of the solution. In this phase, the fiber optic network is replaced on one or two cages with a wireless 5G communication set up, which must meet the demands for data traffic and stability.

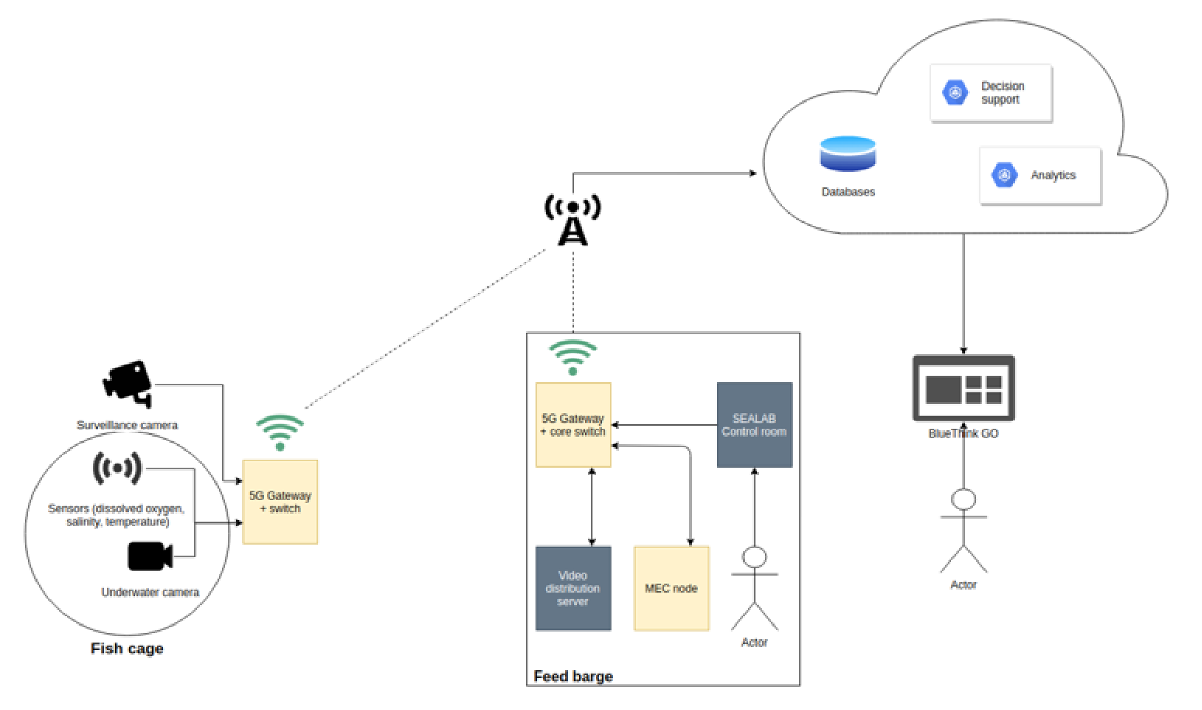


Figure 17: Norwegian pilot – user architecture scenario A1S5.

6.2.3 Hardware components

In addition to the hardware components used in A1S1, A1S2 and A1S4 the following components are needed:

- Video distribution server on the 5G base station.
- 5G-CPE's on the wireless cages.

6.2.4 Software components

Communication of metrics, control signals, etc. within a farm when every cage has a separate gateway can be achieved in two different ways:

1. Keeping the Message Queuing Telemetry Transport (MQTT) broker on the barge like in the previous cases, but allowing external traffic on port 8883 to reach the MQTT broker. This will require a port forwarding in the 5G gateway.
2. Moving the on-site MQTT broker from the feed barge to a cloud-hosted virtual machine to ensure every software component can reach the MQTT broker.

For the video case, a server running Wowza Streaming Engine on the barge is to be used in the same manner as described in A1S2. The key difference is that video ingress will have to go through the 5G gateway on the feed barge, meaning that devices in the cages have to be able to access the public IP of the barge gateway and a public port (preferably 1935) has to be forwarded to port 1935 on the video distribution server for video ingress. SEALAB can adapt to other choices of public port if necessary.

6.3 Testing and Verification

The testing and verification are common for all the scenarios of the aquaculture use case and thus presented in a separate section later in the document (Section 7) providing details on the analysis of the methodology, key performance indicators, testing tools and initial results for both pilots, the Greek and the Norwegian pilot in Sections 7.1.1 and 7.1.2, respectively.

6.4 Next step plans

The wireless communication equipment is going to be installed alongside the rest of the equipment to allow the proceeding execution of the trials for this scenario. The design for these installations is going to be studied alongside carrying out A1S1, A1S2 and A1S4 in D5.2 Section 2.2.3.2 Hardware components/Norwegian pilot [1], while the actual installations and testing are going to take place during Phase 3. Part 2 of A1S5 where several cages will be wireless, is going to be based on the results from part 1, where only one or two cages communicate over the 5G network. This will start up as soon as possible after a new production starts up again on Gjerdinga, estimated to be in April 2022.

For the network architecture evolution and setup, please refer to section 2.3 (A1S1).

7 TESTING AND VERIFICATION

The testing and verification are common for all the scenarios of the aquaculture use case described in the previous sections. The analysis of the methodology, key performance indicators, testing tools and initial results in the two pilots is provided below.

7.1.1 Testing and verification in the Greek facility

For the 5G-HEART network based on 5G-EVE in the Greek facility, commercial monitoring and testing tools are used by ACTA to check the End-to-End (E2E) network performance, in addition to 5G-EVE ping and iperf tools [8], [9].

The tools are used during the deployment of the 5G-HEART network, as well as during operation.

7.1.1.1 Methodology

One part of the methodology are the trials execution and collection of Quality of Service (QoS) technical KPI metrics from the network equipment. Another part takes place after the trials execution and analyses the collected metrics. Finally, the KPI values are validated by comparison with the predefined target values.

As described in D5.2 Section 2.3.2 Testing and Verification, Section 2.3.2.1 Methodology [1], the Two-Way Active Measurement Protocol (TWAMP) will be used by ACTA for the measurement of Latency, Jitter and Packet Loss (Figure 10). TWAMP uses the methodology and architecture of the One-way Active Measurement Protocol (OWAMP). The OWAMP, specified in RFC4656 [9], provides a common protocol for measuring one-way metrics between network devices. OWAMP can be used bi-directionally to measure one-way metrics in both directions between two network elements. However, it does not accommodate round-trip or two-way measurements. TWAMP is an open protocol for measurement of two-way or round-trip metrics in addition to the one-way metrics of OWAMP and allows continuous measurements (24h basis) with traffic covering fully all the use case trial periods. In this case, TWAMP is going to be used for measurements over ethernet. The use of the improved TWAMP protocol will provide better accuracy compared to the widely used Internet Control Message Protocol (ICMP) for the active measurements.[9][10][11]
TWAMP employs time stamps applied at the echo destination (reflector) to enable greater accuracy. TWAMP consists of two inter-related protocols: TWAMP-Control and TWAMP-Test. TWAMP-Control is used to initiate, start, and stop test sessions, and TWAMP-Test is used to exchange test packets between two TWAMP entities.

The TWAMP-Control and TWAMP-Test protocols accomplish their testing tasks as outlined below:

- The Control-Client initiates a Transmission Control Protocol (TCP) connection on TWAMP's well-known port, and the Server responds with its Greeting message, indicating the security/integrity mode it is willing to support.
- The Control-Client responds with the chosen mode of communication and information supporting integrity protection and encryption, if the mode requires them. The Server responds to accept the mode and give its start time. This completes the control-connection setup.
- The Control-Client requests a test session with a unique TWAMP-Control message. The Server responds with its acceptance and supporting information. More than one test session may be requested with additional messages.
- The Control-Client initiates all requested testing with a Start-Sessions message, and the Server acknowledges.
- The Session-Sender and the Session-Reflector exchange test packets according to the TWAMP-Test protocol for each active session.
- When appropriate, the Control-Client sends a message to stop all test sessions.

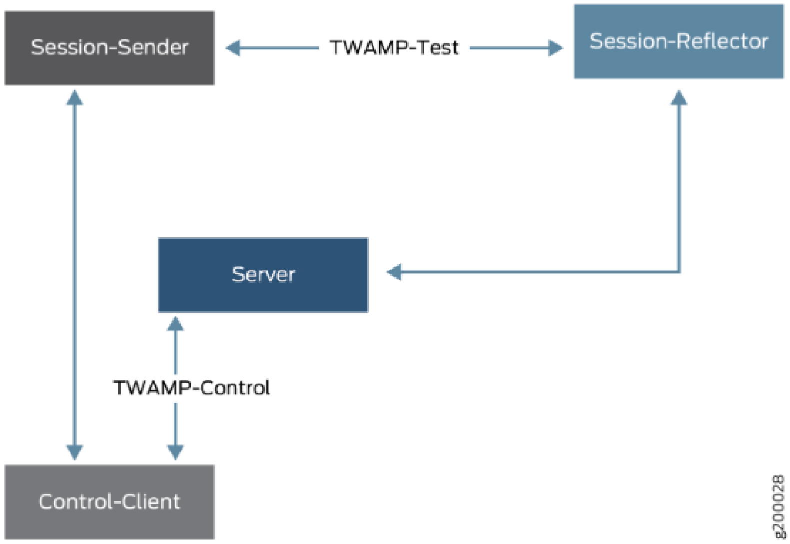


Figure 18: The four elements of TWAMP.

For time related KPI measurements like latency (one-way or round-trip), jitter, etc. it is very common to use ICMP based packet (most commonly referred to as PING). This is mostly a connectivity tool when the network infrastructure is being established or a new node is installed and configured. For more accurate time measurements, the Two-Way-Active-Measurement Protocol (TWAMP) is more appropriate. The TWAMP protocol is used by Network equipment manufacturers (Cisco, Nokia, Huawei, Ericsson, Juniper etc.). The official RFC5357 can be found in the IETF repository [10].

A brief table overview of the comparison between PING and TWAMP is show in below.

Table 2: TWAMP vs. PING comparison for time based measurements.

Capability	**TWAMP**	**ICMP echo (ping)**
Original Scope	Performance monitoring across IP networks	Connectivity check, Crude round-trip delay capability
Monitoring of existing Infrastructure	Available in certain routers, network equipment, Network Inteface Devices (NID)s, probes	Yes (almost universal support in every Network Element (NE), Operating System)
Transparency through network elements allowing generic, robust, predictable test methodology	Yes (User Datagram Protocol (UDP) traffic-based test, passes through network)	In some installations, routers block or rate limit ICMP
Round Trip Delay KPI	Yes	Insufficient accuracy due to slow ICMP processing in network elements
1-way Loss KPI	Yes	No
1-way Delay KPI	Yes	No
1-way delay variation (PDV) KPI	Yes	No

For the evaluation of the throughout KPI, ACTA will apply the evaluation procedures described in 3GPP TS 28.552 [11] standard, that is related to the management and orchestration of 5G performance measurements and to the 3GPP TS 28.554 [12] standard that specifies the end-to-end KPIs for the 5G network and network slicing. The selection of one or the other protocol is based on the granularity of the throughout measurements. In case, that we would validate the throughput in a per UE basis, then the 3GPP TS 28.552 standard will be adopted. In cases that the accumulated throughput of a network slice will be evaluated, the 3GPP TS 28.554 will be used.

The use of real-time network and service KPI acquisition, together with the subsequent analysis of the measurements, allows for pre-emptive resolution of network and service delivery issues.

7.1.1.2 List of Key Performance Indicators

NTUA and ACTA have identified a set of network KPIs as described in D5.2 [1] Section 2.3.2 Testing and Verification, 2.3.2.1 Methodology to be evaluated in the scenario A1S1 and that are also applicable to scenarios A1S2 and A1S3. These KPIs comprise metrics related to the service provided to the end users as well as to the operation of the network. The definition of each KPI is presented below.

Table 3: KPI definitions.

UC A1S1 KPIs	Definition
UL Max throughput (Mbps)	Throughput is the amount of information transmitted per unit of time. Throughput is usually measured in bits per second (bit/s or bps). User experienced data rate (bps) is a minimum achievable data rate for a user in real network environment. Peak data rate (bps) is a maximum achievable data rate per user.
DL Max throughput (Mbps)	
UL latency (ms)	Latency is the time it takes to transfer a first/initial packet in a data burst from one point to another.
DL latency (Ms)	
UL jitter (ms)	Jitter is the deviation from true periodicity of a periodic signal. Jitter can be quantified in the same terms as all time-varying signals, e.g., Root Mean Square (RMS), or peak-to-peak displacement. Also, like other time-varying signals, jitter can be expressed in terms of spectral density.
DL jitter (ms)	
UL frame loss (%)	Frame loss is the percentage of the number of service frames not delivered in relation to the total number of service frames sent, during a specific time period.
DL frame loss (%)	
UL Packet loss (%)	Packet loss occurs when one or more packets of data travelling across a computer network fail to reach their destination. Packet loss is either caused by errors in data transmission, typically across wireless networks, or network congestion. Packet loss is measured as a percentage of packets lost with respect to packets sent.
DL Packet loss (%)	

As described in D5.1 Section 2.2.3.3 Key Performance Indicators/Greek site [13], accurate and effective testing, for service and network KPI measurement and validation, will be introduced in order to verify the expected level of network quality. The KPI Management and Validation Platform (KMVaP) via the use of Network probes, positioned in key interface parts of the end-to-end network, will accumulate appropriate network parameter metrics at various points of the live network. Service path segmentation will be applied in order to identify the parts of the network mainly affecting the KPI values. Measurements will be collected both before the use cases start running and also during the use cases pilot period.

The measurements will be transmitted and stored to a Cloud Server for further processing. Measurements relate to latency, reliability, data rates, and other measurements, that are essential in validating the network KPIs. Furthermore, the large amount of data will be analysed and presented in a user-friendly format in order to identify possible weak points and undertake corrective action for network optimization and performance improvement. The last two eventually lead to improved end-user experience and service acceptance.

Table 6 summarises a preliminary list of KPIs of interest, which will be refined in the next stages of the project. It includes the specific requirement values mentioned Table 1 above, as well as the KPIs specific to the vertical.

Table 6: Key Performance Indicators for the Greek site on the 5G-EVE platform.

		Units	5G paradigm			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case KPI								
1	Latency (in miliseconds) - round trip - Min/MAX	msec				High	10	50
2	RAN Latency (in milliseconds) - one way	msec				High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand (Uplink)	Mbps				High	15	50
4	Reliability (%) - Min/MAX	%	99.9999	99.9999	99.9999	High		
5	Availability (%) - Min/MAX	%	99.99	99.99	99.99	High		
6	Mobility (in m/sec or Km/h) - Min/MAX	km / hour	10	10	10	Low		
7	Broadband Connectivity (peak demand)	Mbps				High	15	50
8	Network Slicing (Y/N) - if Y deployment time (min)	Y/N	y	Y	Y	High		
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	y	Y	Y	High		
10	Capacity (Mbps/m^2 or Km^2)	Mbps /km^2				High	300	1000

11	Device Density [2]	Dev/ Km^2				High		100
12	Location Accuracy[3]	m	0.1			Medium		
Specific Vertical/KPI								
Network KPI	Number of End Points		10	10	10			
	Number (Range) of End Devices per End Point		50	50	50			
	Density of End Devices (per sq. kilometer)		100	100	100			
	Bitrate needs per end point (Kbps,Mbps, Gbps)	Mbps					15	50
	End -to-end Latency (msecs)						10	50
	Highest Acceptable jitter (msec)		2	2	2			
	Number of Class of Service / QoS (1-8, more)		1	1	1			
End Devices	Type of Device (i.e. Smartphone, TV, VR)		Drone	Sensor	Camera	360-degree cameras		
	Bitrate required (Kbps / Mbps / Gbps)		15-50 Mbps	250-500 Kbps	15-50 Mbps	15-50 Mbps		
	Max Latency Allowable (in msecs)		10	1000	1000	20		
	Max Moving Speed (km/h, 0 if stationary)		10	0	0	0		

[2] Device density refers to end-devices, meaning sensors, cameras, drones

[3] Network Operator provide location at the 5G-Gateway level. Internal component location will be provided by internal mechanism on each of the two pilot facilities in 5G-HEART.

	IPv4 & IPv6 support (or both)		both	Both	Both	IPv4		
	Connection of Device to End Point (Wired/Wireless)		Wireless	Wired	Wired	Wired		
	Type of Connection (i.e. Ethernet, WLAN, Zigbee)		Sonar/Ethernet	Ethernet	Ethernet	Ethernet		
	Authentication method (i.e. SIM, eSIM, Key..)		SIM	SIM	SIM	-		
Other Vertical Specific (non-Network related Requirements)								
	Battery life requirement (years)		15	15	15	-		
	Power source					PoE		

7.1.1.3 Measurement and Testing Tools - ACTA Network probes and Management System

The measurement and testing tools are described in detail in D5.2 Section 2.3.2.1 [1].

ACTA has assisted in the network rollout and activation by measuring network KPIs and validating the level of performance achieved. These KPIs comprise of metrics related to the service provided to the end-users (such as latency, data rate, etc.) as well as others related to the operation of the network (such as deployment time and scalability).

ACTA’s platform has both the ability to monitor the traffic passing through the network (user traffic) and extracting important KPIs such as bandwidth utilisation and transfer speeds per service, as well as active testing (generate test traffic) which is used to measure packet loss, delay and jitter information for selected network paths.

ACTA’s implementation is based on both hardware and software probes managed by a dedicated cloud platform. These elements are described in the following sections.

The following Viavi [12] hardware network probes are deployed in key positions in the network (Figure 19 and 20).

MTS-5800 Handheld Network Tester

Figure 19. The Viavi M TS-5800 probe.

The Viavi MTS-5800 handheld network tester can test throughout the service life cycle, including, service activation, troubleshooting, and maintenance. Advanced Ethernet test features such as throughput testing with TrueSpeed per RFC 6349 have also been employed.

Viavi JMEP

Figure 20. Viavi SFP network probe (JMEP).

The VIAVI JMEP micro Ethernet probe for Ethernet and IP performance assurance, are gigabit Ethernet smart SFP transceivers, available in two varieties, a 1 Gbps JMEP3 and a 10 Gbps JMEP10, that both can seamlessly be deployed inline into existing network devices. The Small Factor Pluggable (SFP) main capabilities are:

- Fully compatible with RFC 2544 and Y.1564 test methodologies [14][15]
- Activates test loopbacks (L2/L3)
- TWAMP-Light (RFC 5357)
- Measures throughput, availability, frame loss, frame delay, and frame delay variation.

These probes are being complemented with Software (SW) based measurements and virtual probes that reside in the ACTA KMVaP cloud platform, described in the following section.

The KMVaP is the central management system for the multitude of probes that are installed in the network and are responsible for collecting data from measurements of network KPIs. These additional probes include (and are not limited to):

Fusion TrueSpeed VNF

Throughput testing as a virtual network function based on RFC 6349.

Based on the IETF RFC 6349 TCP throughput testing methodology, Fusion TrueSpeed Virtual Network Function (VNF) performance tests serve as a neutral 3rd-party evaluation of network quality. Operating as a VNF in conjunction with VMware hypervisors, Red Hat Linux, and x86 compute resources, Fusion TrueSpeed VNF deploys quickly and tests reliably in all parts of the network.

VCPE1 Software based probe
The hardware of VCPE1 probe consist of a SUPERMICRO SERVER 5019D-4C-FN8TP CPU: INTEL SoC Intel® Xeon® processor D-2123IT, 4-Core, 8 Threads, 60W RAM:16GBDDR4-26662Rx8ECCREGDIMM DISK DRIVE: Samsung PM883 240GB SATA 6Gb/s V4 TLC 2.5" 7mm (1.3 DWPD)

Figure 21. The Virtual CPE/ Software Probe hardware used in the KMVaP platform.

Being a virtual software probe and VCPE can host a number of different probe functionalities tailored to the measurements required by the network operator and/or Vertical user.

ACTA KMVaP architecture, components and software
The network probes and their measurements are managed via ACTA's in-house developed KPI Measurement and Validation Platform (KMVaP).

The interconnection of the platform with OTE's LAB infrastructure is shown in Figure 22 together with the Public IP address that is used for Remote Management, Remote Configuration and Access to the collected data by third parties. Connectivity has been established between Skironis site and OTE Labs over VLAN 443 / 10.10.9.0/24.

The overall placement of the KMVaP platform and the probes with respect to the ICT 19/22 projects (5G EVE) infrastructure are also shown in Figure 22.

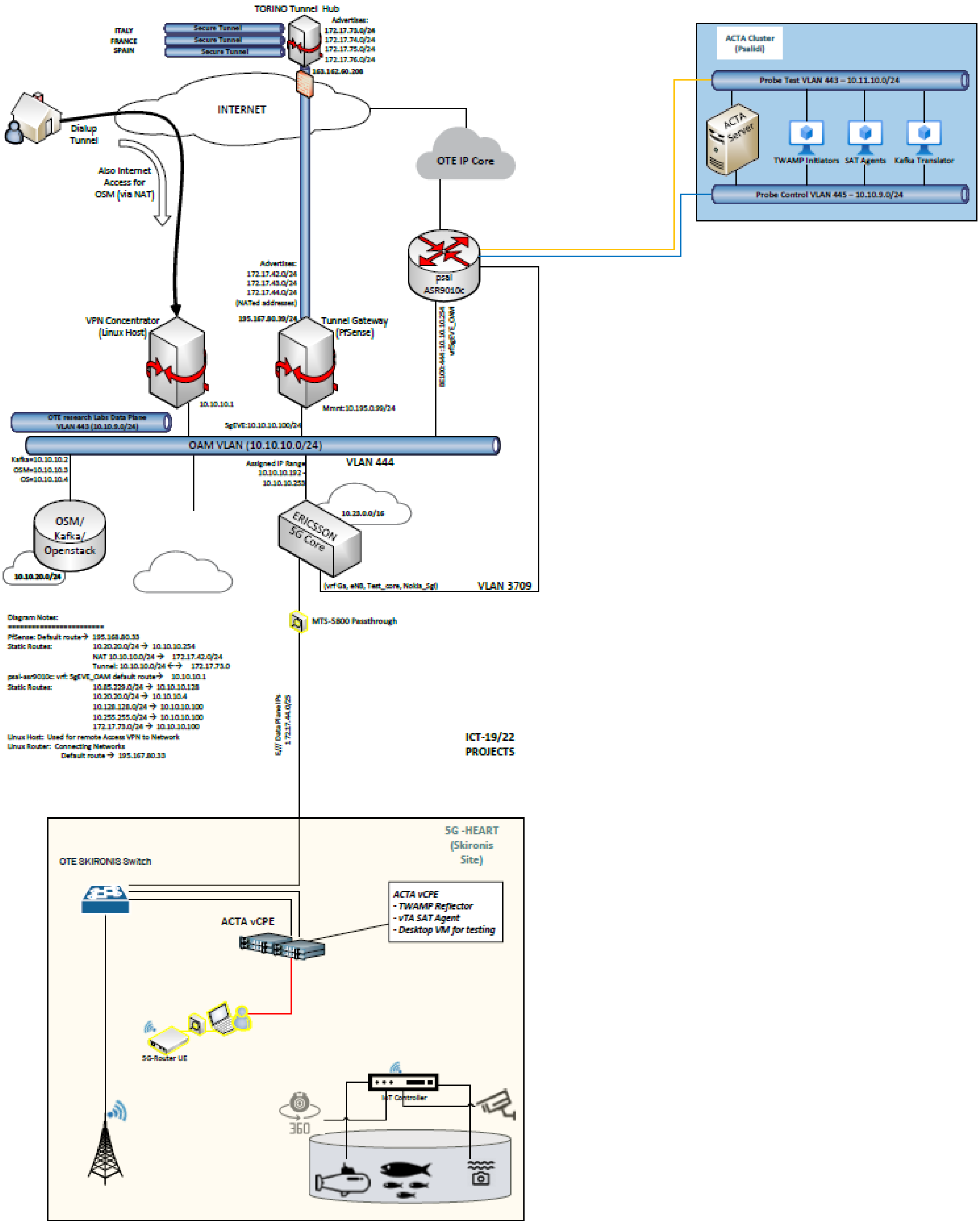


Figure 22. Overall network architecture of 5G HEART with respect to 5G EVE network.

The actual installation of the probes in the Skironis site is shown in Figure 23 below.

Figure 23: Virtual probes connected in OTE switch at Skironis site.

The actual ACTA installation at OTE Labs can be seen in Figure 24Figure 23 below.

Figure 24: ACTA's KMVaP ecosystem at OTE Labs

The internal Architecture of the KMVaP (KPI measurement and validation platform) that is installed in OTE-group R&D Laboratories is shown in Figure 24.

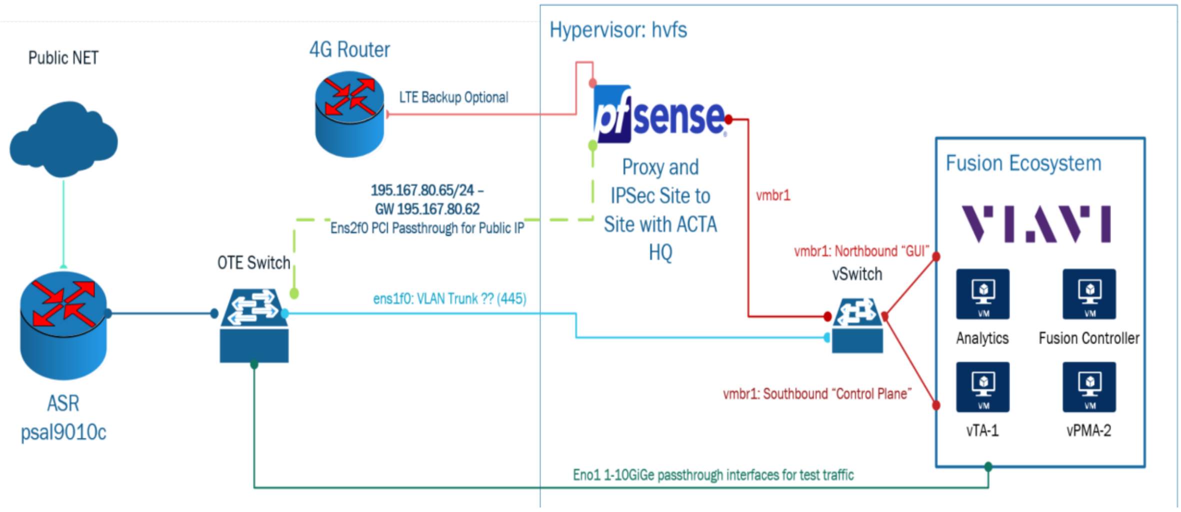


Figure 25: ACTA's KMVaP ecosystem for KPI measurement and validation.

The core part of the KMVaP cental management system is based on VIAVI's Network Integrated Test, Real-time analytics and Optimization (NITRO) [16] platform. This is augmented by Open-Source components and ACTA developed software in order to become a complete KPI validation system.

All the components of the KMVaP platform are Virtual Machines using a VM Hypervisor (hvfs). A hypervisor [17], [18] (or Virtual Machine Monitor (VMM), virtualizer) is computer software, firmware and hardware that creates and runs virtual machines. A computer on which a hypervisor runs one or more virtual machines is called a host machine, and each virtual machine is called a guest machine. The hypervisor presents the guest operating systems with a virtual operating platform and manages the execution of the guest operating systems. Multiple instances of a variety of operating systems may share the virtualized hardware resources: for example, Linux, Windows, and macOS instances can all run on a single physical x86 machine. This contrasts with operating-system-level virtualisation, where all instances (usually called containers) must share a single kernel, though the guest operating systems can differ in user space, such as different Linux distributions with the same kernel.

A KAFKA [19] interface is enabled in the KMVaP management Platform that is delivering the measurements in real-time to the KAFKA topic defined in the KAFKA server with IP address 10.10.10.2 (shown in the figure above). With the translation of the measurement data from the ACTA VIAVI Fusion Kafka topics format to the 5G-EVE KAFKA topic format, we achieve to use the 5G-EVE environment and the Analysis and Diagnosis software components developed by NTUA. Also, the EVE KAFKA SW modules are used by many Projects. This will be an automated process running 24x7, with 1min monitoring granularity and 10 ms sampling granularity.

Table below summarises the protocols and KPIs that are monitored.

Table 7: Summary of network protocols and KPIs.

Type	**Probe type**	**Direction**	**KPI L2/L3**	**KPI L4**
SAT - RFC2544 - Y.1564	MTS 5800	Bidirectional		Service Activation Testing
			Throughput	peak throughput
			Latency	Latency
			packet loss	packet loss
				Availability

PM - TWAMP - RFC5357	SFP & Virtual	Bidirectional		
			Latency	
			packet loss	
			Delay variation (jitter)	
WireSpeed - RFC6349 (TrueSpeed)		Bidirectional		peak throughput (TCP)

The system includes both the ability to monitor the traffic passing through the network (user traffic) and extracting important KPIs such as bandwidth utilisation and transfer speeds per service, as well as active testing (test traffic) which provides packet loss, delay and jitter information for selected network paths.

7.1.1.4 Architectural Approach

An architectural approach has been designed to support the data aggregation, data management and data analysis phases for 5G network management. The approach is depicted in Figure 26.

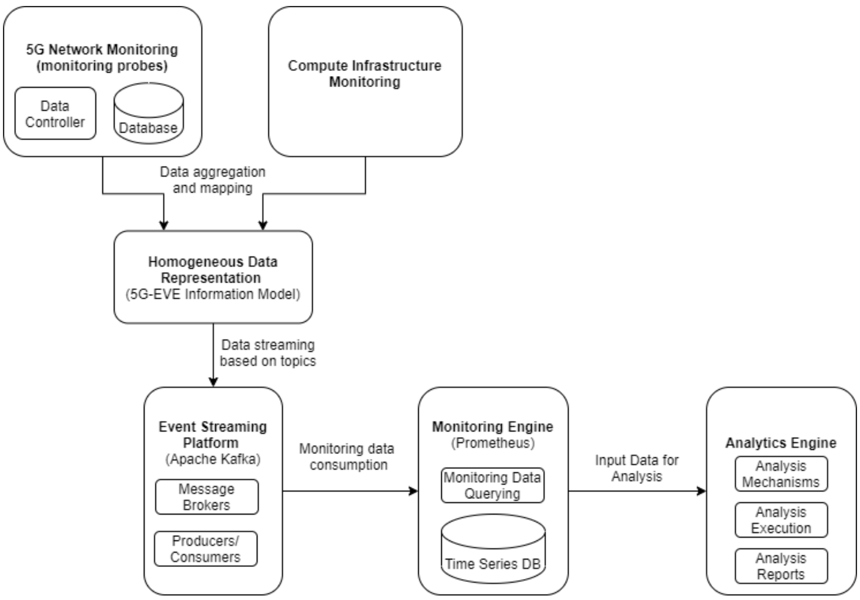


Figure 26: 5G Infrastructure Data Monitoring and Analysis Approach.

A set of monitoring probes are made available for data collection over the deployed 5G infrastructure. These probes include both network monitoring probes and compute resources usage' monitoring probes. Network monitoring probes include hardware and software probes that provide Quality of Service (QoS) data for the various core, transport and access links. Compute resources usage' monitoring probes regard data for the consumption of resources (e.g., CPU usage, memory usage) by the deployed application components and/or VNFs. To achieve end to end measurement of QoS metrics, the various probes communicate with a central data controller software for configuration, management and data-measurement acquisition and storage purposes. In the 5G-HEART infrastructure for the aquaculture use case, this software is provided by ACTA (ACTA KPI Measurement and Validation Platform - KMVaP). Regarding the resource usage metrics, data is collected by the relevant modules in the orchestration ecosystems that are used (e.g., Kubernetes, OpenStack).

Upon the collection of the data, a homogenization process takes place to guarantee data interoperability across platforms. The 5G-EVE information model is being used for this purpose. For each metric, the collected data include information for the measured value, the timestamp, the unit of measurement and the id of the associated device or link. Following, the data is provided in the form of data streams to an event streaming platform, namely the Apache Kafka platform. For each metric, a specific topic is defined where the data can be published and made available to all the subscribers.

One of the subscribers is the Monitoring Engine that it regards a Prometheus [20] instance. Prometheus acts as a subscriber in a series of topics that are populated in the Event Streaming Platform. Each time a new value is made available to the Message Brokers, it is also consumed by the Monitoring Engine. In the latter, the data is also made available in a time series database and can be used for visualisation or analysis purposes.

Querying interfaces are made available from Prometheus for fetching specific views of the available data. Through such interfaces, data is fed for analysis purposes in the Analytics Engine. The Analytics Engine has onboarded a set of algorithms that can be executed over time series data. The objective is to get insights regarding the 5G networks operation, support network planning processes and inject intelligence in orchestration mechanisms to increase automation. The supported algorithms include forecasting modules, regression analysis and correlation mechanisms and Machine Learning (ML) mechanisms. Per executed analysis, a report is produced and made available to the application providers or the network administrators.

Analytics Engine

The Analytics Engine regards an open-source software that has been developed to enable network application or service providers to easily execute analysis processes and have access to the produced results [21]. It is based on the usage of open-source tools and the specification of open Application Programming Interfaces (APIs) for interacting with the various components in the proposed architectural approach. In the work presented in this manuscript, the Analytics Engine has been modified to be able to consume data that are represented based on the 5G-EVE information model, as well as to properly consume data from the Monitoring Engine. A dashboard has been also developed to make the overall process easily adoptable by network and system administrators, as well as data scientists.

The end user is able to select and configure the algorithm to be used for the analysis, select the set of monitoring metrics and the time period to be considered. Following, the algorithm is executed and the produced results are made available in the form of an online report, while they are also stored in a repository. At the moment, execution of analysis scripts written in Python and R is supported. Furthermore, an API has been made available for onboarding of analysis scripts. In this way, scripts made available by data scientists can be easily integrated and exploited by the Analytics Engine.

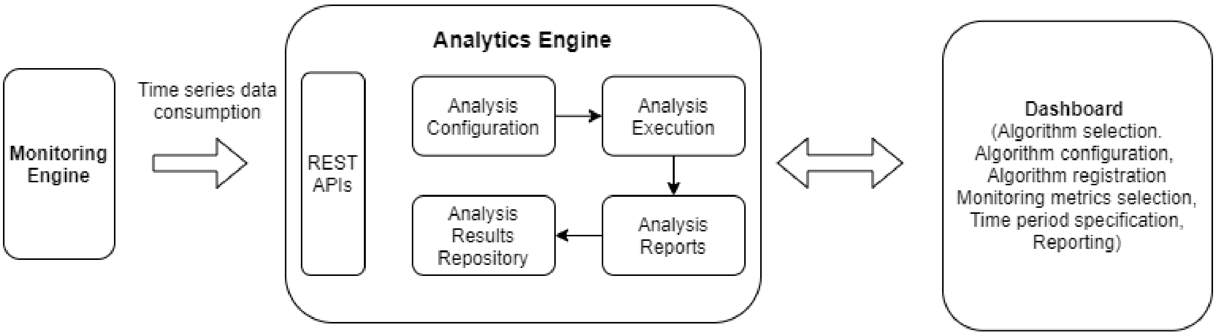


Figure 27: Analytics Engine Components.

Focus is given on the openness of the tool towards data scientists, facilitating the ease of integration and usage of analysis processes. The data scientist is able to develop and onboard analysis scripts for supporting specific types of analyses. Such scripts can be developed in R or Python. These scripts are then made available to the end users of the Analytics Engine for performing analyses over the collected time series data. The supported analysis processes at the current phase include algorithms for time series decomposition (identification of seasonalities and trends and support of forecasting), (multiple) linear regression (identification of correlation among dependent and independent variables) and correlograms (check statistically significant correlations among numerous variables).

A user interface has been also developed (based on Vue.js [22]) that provides access to the end user to the various services supported by the Analytics Engine. Per experiment, the end user is able to manage the analysis processes that are executed and acquire access to the produced results. Following, in Figures 20 and 21, two indicative screenshots from the developed user interface is depicted.

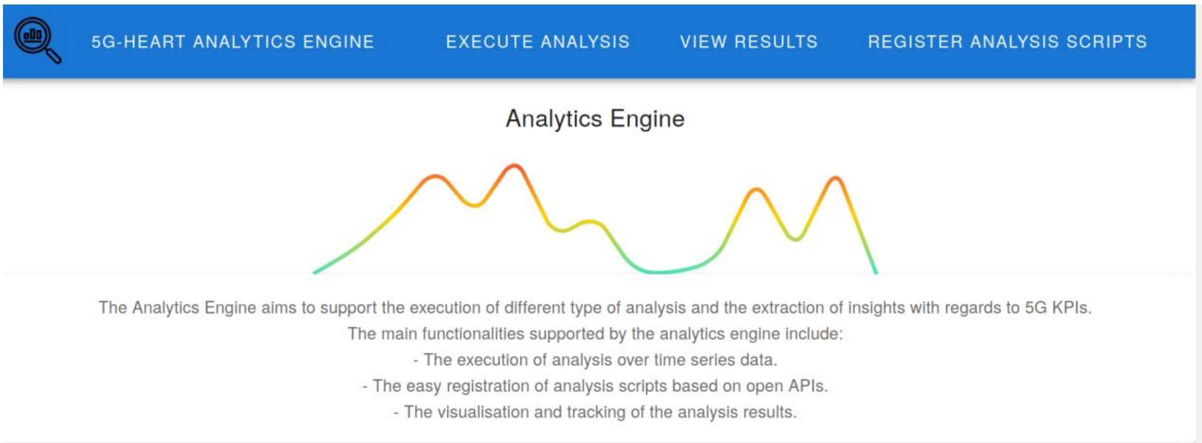


Figure 28: Analytics engine landing page.

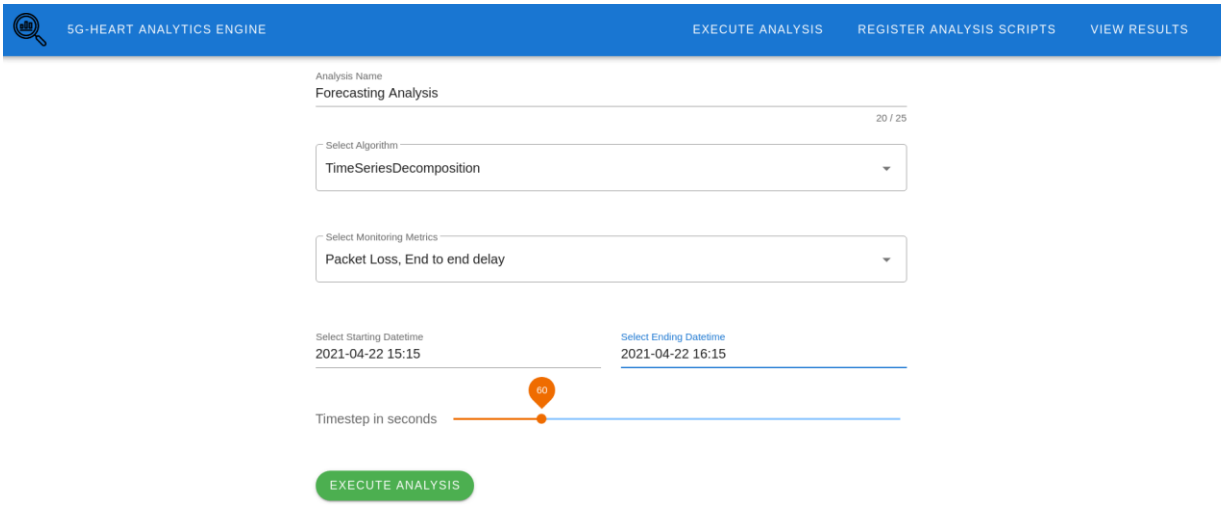


Figure 29: Configuration of an analysis process.

7.1.1.5 Intermediate Results

Initial results have been reported in D5.2. Section 2.3.2.4 [1].

During Phase 2, ACTA has been working on the preparation of several test measurements scenarios in cooperation with OTE, WINGS and NTUA.

The transport network between OTE Labs and Skironis has been shown to provide excellent characteristics, in terms of latency, Round Trip Time (RTT) and throughput. Namely, L4 TCP test traffic Service Activation Testing SAT (RFC 6349) has resulted as shown in Figure 30 to:

- 949 Mbps throughput (out of 1 Gbps capacity)
- 0% packet loss

- 1,34 ms RTT

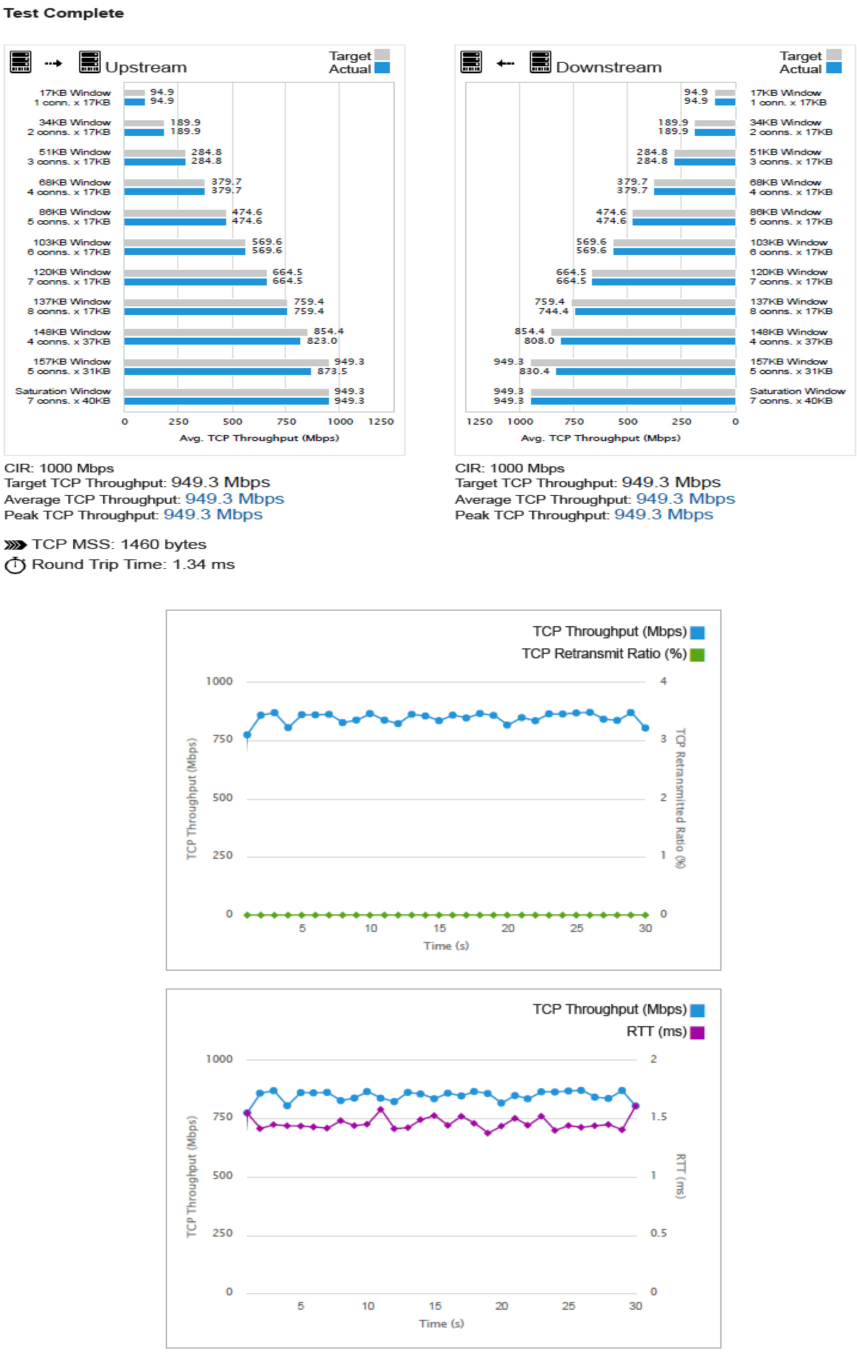
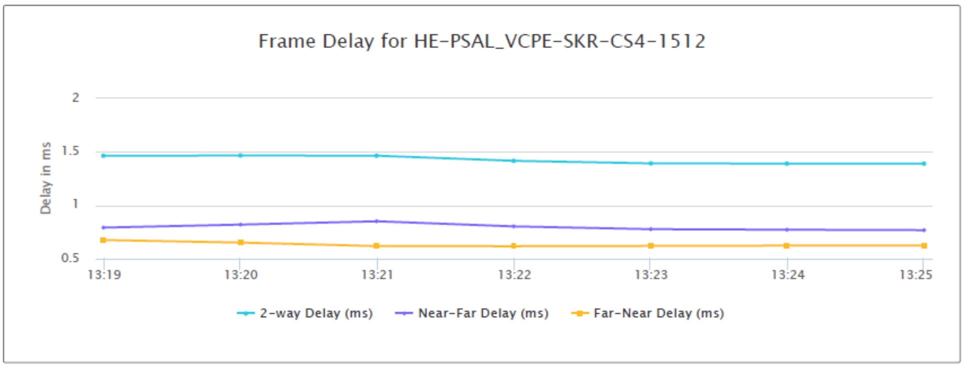


Figure 30: L4 Test traffic (TCP) measurements 5G HEART Aquaculture transport network.

While the delay, jitter and loss parameters of the network (TWAMP (RFC 5357) – L3 KPIs) have been measured as shown in Figure 31 as:

- 1,5 ms delay
- 0,05 ms jitter
- 0% Frame loss



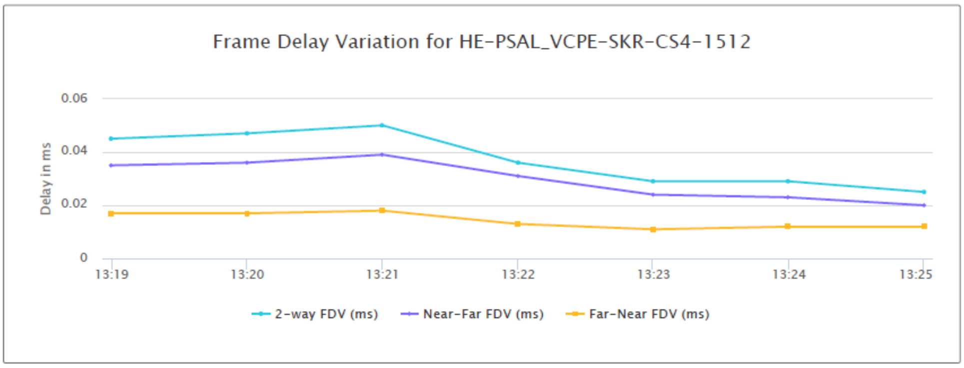


Figure 31: L3 Delay and jitter measurements 5G HEART Aquaculture transport network.

During the next phase, at the Greek site, additional sensor installations are going to follow, such as TWAMP reflectors in Ericsson Baseband Units (BBUs) and an outdoor rugged router, to allow better segmentation of the measurements, once 5G traffic is offered.

In parallel, the results of the collaboration with WINGS and NTUA on KPI metrics transfer to 5G-EVE Kafka server and analysis will be tested with live data.

7.1.2 Test and verification in the Norway Facility

The 5G-VINNI Testing-as-a-Service (TaaS) platform offers a wide range of testing tools. These include both tools for testing of the 5G-VINNI core and more general tools for testing traffic to and from user devices.

TaaS allows the user to define test campaigns that consist of a combination of test cases with different parameter settings. There is a large number of pre-defined test cases that the user can select from. Users can also define their own test cases. TaaS also allows the users to schedule tests, both single tests and tests that are performed at regular intervals.

The TaaS platform and relevant KPIs are described in more detail in D5.2 [1].

7.1.2.1 Methodology

<u>Methodology for network-level measurements</u>

The measurements of the network layer KPIs will be performed using the TaaS tools described in D5.2 [1]. Different locations will be identified within the expected coverage area of the 5G-VINNI gNB to measure up- and downlink throughput, latency and signal strength (downlink). Note that the backhaul between the 5G-VINNI core and this site is limited to maximum 1 Gb/s, this will limit the overall performance of the site.

Methodology for application level measurements

The measurement procedure for the application KPIs will vary depending on what is beneficial in each case, in certain cases that will be the subjective opinion of the end user.

7.1.2.2 List of Key Performance Indicators

Network KPIs

The user requirements associated with these use case scenarios have been analysed and converted into a set of network KPIs in D2.2 [23]. Table 4 presents the resulting list of network requirements together with their target values.

Table 4: Target KPIs for A1 scenarios.

No	Network Requirements	A1S1	A1S2	A1S3	A1S4	A1S5
1	User experienced Downlink (DL) throughput	Low ≤ 1 Mbps	1 Mbps (Low)	1 Mbps (Low)	5 Mbps (Medium)	100-200 Mbps (High)
2	User experienced UL throughput	1 Mbps - 2 Mbps (Medium)	100-200 Mbps (High)	20 Mbps (High)	100 Mbps (High)	100-200 Mbps (High)
3	Broadband connectivity / peak data rate	Uplink: 2 Mbps (Low) Downlink: 1 Mbps (Low)	Uplink: 200 Mbps (Low) Downlink: 1 Mbps (Low)	Uplink: 100 Mbps (Low) Downlink: 1 Mbps (Low)	Uplink: 100 Mbps (Low) Downlink: 5 Mbps (Low)	Uplink: 200 Mbps (Low) Downlink: 200 Mbps (Low)
4	Latency requirements	100ms (Low)	5 ms (High)	5 ms (High)	High < 5 msec	5 ms (High)
5	Reliability	High - 99.99999 %	High - 99.99999%	High - 99.99999%	High - 99.99999%	High - 99.99999%

6	Mobility	Low ≤ 50 Km/h	Low ≤ 50 Km/h	Low ≤ 50 Km/h	Low ≤ 50 Km/h	Low ≤ 50 Km/h
7	Location accuracy	Low > 25 meters	Low > 25 meters	Medium ≤ 25, > 1 meters	Low > 25 meters	Medium ≤ 25, > 1 meters
8	Connection (device) density	Average: 103 devices/km2 Peak: 13.2×103 devices/km2	Average: 100 devices/km2 Peak: 1.2 ×103 devices/km2	Average: 150 devices/ km2 Peak: 103 devices/km2	Average: 125 devices/ km2 Peak: 1.5 ×103 devices/ km2	Average: 145 devices/ km2 Peak: 1.74 ×103 devices/km2
9	Interactivity	Medium > 1, ≤ 100 transactions/sec	Medium > 1, ≤ 100 transactions/sec	Medium > 1, ≤ 100 transactions/sec	Medium > 1, ≤ 100 transactions/sec	Medium > 1, ≤ 100 transactions/sec
10	Area traffic capacity	DL: 0.001 Mbps/m2 (average) DL: 0.00132 Mbps/ m2 (peak) UL: 0.002 Mbps/ m2 (average) UL: 0.00264 Mbps/ m2 (peak)	DL: 0.0001 Mbps/m2 (average) DL: 0.0012 Mbps/ m2 (peak) UL: 0.02 Mbps/ m2 (average) UL: 0.24 Mbps/ m2 (peak)	DL: 0.00015 Mbps/ m2 (average) DL: 0.001 Mbps/ m2 (peak) UL: 0.003 Mbps/ m2 (average) UL: 0.02 Mbps/ m2 (peak)	DL: 0.000625 Mbps/ m2 (average) DL: 0.0075 Mbps/ m2 (peak) UL: 0.0125 Mbps/ m2 (average) UL: 0.15 Mbps/ m2 (peak)	DL: 0.029 Mbps/ m2 (average) DL: 0.348 Mbps/ m2 (peak) UL: 0.029 Mbps/ m2 (average) UL: 0.348 Mbps/ m2 (peak)
11	Security / privacy	Medium: Restricted	Medium: Restricted	High: Confidential	High: Confidential	High: Confidential

Application KPIs

In addition to the analysis of the user requirements made in D2.1 [24], a series of application specific KPIs are being defined to assess the high-level needs of the solutions as shown in Table 5.

Table 5: Application KPIs for A1 scenarios.

KPI	Description
Power consumption	Power/energy consumption measured for User Equipment (UE) devices that connect to the 5G network in comparison to the corresponding 4G values. When measured, the corresponding overheads from the utilization of different equipment should be considered.
Frame quality	Video frames quality degradation caused from missing packets. Video frames can be reconstructed by powerful re-construction algorithms currently on play, which include an error deviation. This KPI is based on the difference between the original and reconstructed frames. The metric of this difference can be the Euclidian distance or other metric depending on the application. The video resolution can be an important influence factor for the measurements.
Missing frames	Metric to evaluate the rate of missing frames (MF). This can be a percentage or a more complex metric considering the frequency and density of lost frames. The frame rate is a relevant factor that can influence the measurement. MF =Number of missing frames/total number of transmitted frames
Misclassification	Percentage of the lost information-important frames. The information-important frames are the ones that can be used for classification of certain characteristics in comparison to the ones that do not offer any special information. MF=Number of missing information-important frames/total number of transmitted information-important frames
Continuous operation	The maximum time of continuous unavailability of the operation service.
Service availability	The percentage of the operation service availability time
Total reaction time	The time elapsing from an observation collection to its transmission to the cloud and the backwards transmission of a command based on this observation.
Delay	The application latency measured during the transfer of a piece of information.
Live experience	The evaluated performance of the streaming service in terms of MOS. This relates to the video fram quality as well as the delay perceived subjectively to the user.

7.1.2.3 Measurement and Testing Tools

Please refer to D6.3, Section 3.2 [25] for an overview of the 5G-VINNI testing tools.

7.1.2.4 Intermediate Results

An analysis of the expected coverage for the 5G-VINNI site at Gjerdinga has been done. The distance from the gNB to the fish farm site is between 800 and 1000 m, with full line-of-sight for the B-sector. A terrain cross section is in Figure 32.

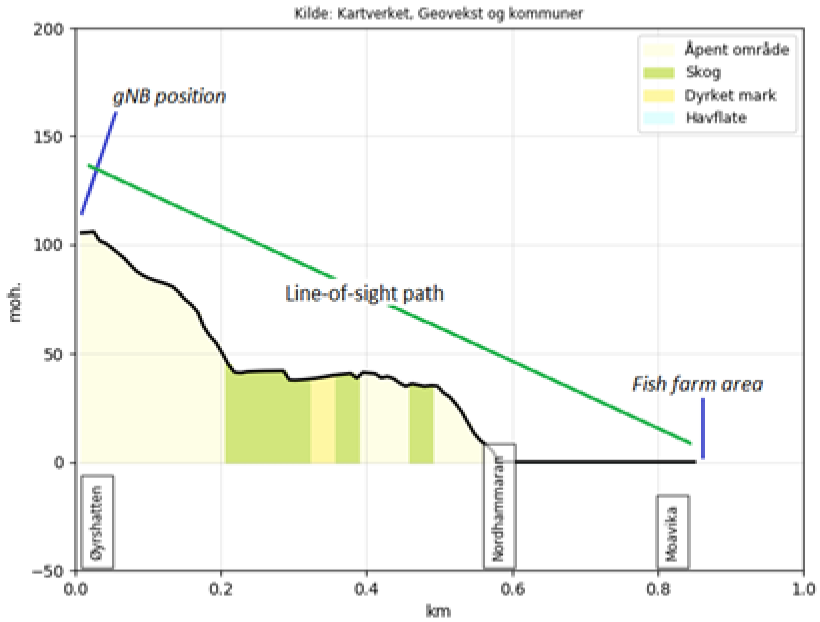


Figure 32: Terrain profile for the radio path between the 5G-VINNI gNB and the Norwegian aquaculture site.

The radio coverage is not expected to be a limiting factor. Table 4Table 6 contains a preliminary analysis of the scenario. The numbers for transmit power and antenna gain at the gNB are typical maximum values. The values for transmit power at the UEs are not yet known.

Table 6: Preliminary coverage analysis of the gNB serving the Norwegian fish farm site.

Common parameters		
Propagation scenario:	Line-of-Sight (LoS); over sea propagation	
Distance:	800 m – 1000 m	
Frequencies	3.6 GHz (3.61 – 3.7)	26 GHz (26.5 – 27.3)
gNB parameters		
Tx output power (max)	33 dBm	36.5 dBm
Antenna (beam) gain:	25 dBi	30 dBi

Effective Isotropic Radiated Power (EIRP):	58 dBm	66.5 dBm
Receiver sensitivity	TBD	TBD
UE parameters		
Tx output power	TBD	TBD
Antenna gain:	0 dBi	0 dBi
Receiver sensitivity	TBD	TBD
Outputs		
Path loss (d=1 km)	101.7 - 103.6 dB	118.8 - 120.7 dB
Expected received level DL	-45.6 - -43.7 dBm	-54.2 - -52.1 dBm
Expected received level UL	TBD	TBD

Since parts of the transmission path is over open sea, deeper fades are expected due to the sea surface reflections, maybe up to 20-30 dB, which again will lead to some outage. A thorough analysis remains to be done.

The serving capacity determines how much traffic can be handled. A full analysis has not been done. The experience with other sites in 5G-VINNI as well as Telenor's commercial network is that C-band (3.6 GHz) can deliver up to 1 Gb/s downlink throughput for a single user, however realistic speeds might be lower. The uplink throughput is much less, around 200 Mb/s, due to the asymmetric Time Division Duplex (TDD) frame structure (4:1). An open question is whether the Multi-User Multiple-Input and Multiple-Output (MU-MIMO) feature of the beamforming technology employed in 5G New Radio (5G NR) can be utilised. The spatial (angular) separation between the far ends of the fish farm area is around 25°, and that might not be enough spatial separation.

The data for 26 GHz is sparse, but measurements on another 5G-VINNI site with 800 MHz bandwidth (4 component carriers) has shown a downlink throughput of up to 3.8 Gb/s in a very close up situation. The uplink throughput has been measured to 420 Mb/s on a 630 m distance. These measurements were done using a test UE, which basically is bulky equipment with an external antenna on a trolley.

8 CONCLUSION

This deliverable reports on the progress made during Phase 2 trials for the aquaculture use case. The work is split in two pilots, one in Athens using 5G-EVE and one in Oslo using 5G-VINNI covering the five scenarios involved, A1S1 to A1S5. The report provides an overview of the work done for the development, onboarding and testing of the evolved solutions towards the shift to Phase 3 where integration and testing of the individual solutions will be completed and the final demonstrations will take place towards the completion of the pilot trials. Phase 2 activities have been performed taking into account any restrictions from the COVID-19 situation and the readiness of the 5G platforms. The document reports the intermediate results from the testing and verification of the evolved solution. The reporting of the progress in Phase 3 and the final results to be obtained will be given in the final deliverable of the aquaculture vertical D5.4 "Final Solutions for Aquaculture Vertical Use of 5G" at the end of the project towards the validation of the 5G technologies.

REFERENCES

[1] "D2.3 5G-HEART Network Architecture and Slice Definition, 5G-HEART, 2021".

[2] "D2.1 Use Case Description and Scenario Analysis, 5G_HEART, 2019".

[3] "D2.2 User Requirements Specification, Network KPIs Definition and Analysis, 5G-HEART, 2020".

[4] "D5.2 "Initial Solution and Verification of Aquaculture Use Case Trials", 2020".

[5] [Online]. Available: https://docs.nvidia.com/cuda/index.html.

[6] [Online]. Available: https://opencv.org/.

[7] [Online]. Available: https://ffmpeg.org/.

[8] "5G-VINNI, "Deliverable D1.4: Design of infrastructure architecture and subsystem v2," 5G-VINNI, 2020.".

[9] "5G-VINNI, "Deliverable D2.1: 5G-VINNI Solution Facility -sites High Level Design (HLD)," 5G-VINNI, 2019.".

[10] C. K. Kahraman Zaim, "Performance Analysis of IP Network Using Two-Way Active Measurement Protocol (TWAMP) and Comparison with ICMP (Ping) Protocol in a Saturated Condition," in *4th International Symposium on Innovative Technologies in Engineering and Science (ISITES2016)*, Alanya/Antalya – Turkey, 2016.

[11] [Online]. Available: https://datatracker.ietf.org/doc/html/rfc4656.

[12] "https://tools.ietf.org/html/rfc5357".

[13] 3GPP Portal, "Management and orchestration; 5G performance measurements," 27 3 2020. [Online]. Available: https://portal.3gpp.org/#/.

[14] 5GPP, "Management and orchestration; 5G end to end Key Performance Indicators (KPI)," 27 3 2020. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3415.

[15] "D5.1 "Aquaculture Vertical Trial Requirements Definition and Execution Plan"".

[16] [Online]. Available: https://www.viavisolutions.com/en-us/literature/enhanced-rfc-2544-single-service-test-brochures-en.pdf.

[17] [Online]. Available: https://www.viavisolutions.com/en-us/literature/y1564-samcomplete-multi-service-test-brochures-en.pdf.

[18] [Online]. Available: https://www.viavisolutions.com/en-us/solutions/nitro.

[19] "https://www.pfsense.org/getting-started/".

[20] "https://en.wikipedia.org/wiki/Hypervisor".

[21] [Online]. Available: https://dzone.com/articles/what-is-kafka.

[22] [Online]. Available: https://prometheus.io/.

[23] A. Zafeiropoulos, E. Fotopoulou, M. Peuster, S. Schneider, P. Gouvas, D. Behnke, M. Müller, P. Bök, P. Trakadas, P. Karkazis and H. Karl, "Benchmarking and Profiling 5G Verticals' Applications: An Industrial IoT Use Case.," in *6th IEEE Conference on Network Softwarization*, 2020.

[24] [Online]. Available: Vue.js - The Progressive JavaScript Framework, https://vuejs.org/ .

[25] "5G-VINNI Deliverables," [Online]. Available: https://www.5g-vinni.eu/deliverables/.

[26] "5G-VINNI, 5G Verticals INNovation Infrastructure, [Online]. Available: https://www.5g-vinni.eu/.".

[27] "D2.3 Final 5G-EVE end to end facility description, 5G-EVE, 2021".