

5GMED



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Nature

PR	Prototype
RE	Report
SP	Specification
TO	Tool
OT	Other

Synopsis	Deliverable D5.2 is the second report for WP5. It identifies and describes every hardware and software component needed to implement UC3 (FRMCS performance and business applications service continuity) and UC4 (Follow-Me Entertainment) in the railway scenario. This document also describes the interfaces between the hardware components and the train (mechanical constraints, electrical power needs...), and the interfaces between software components.
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AUTHORS

Authors in alphabetical order		
Name	Organization	Email
Juan Agustí	COMSA	juan.agustimoreno@comsa.com
Marco Bolona	AXBYD	marco@axbryd.com
Paul Caranton (Main editor)	SNCF	paul.caranton@sncf.fr
Josep Escrig	I2CAT	josep.escrig@i2cat.net
Jad Nasreddine	I2CAT	jad.nasreddine@i2cat.net
Luca Petrucci	AXBYD	petrucci@axbryd.com
Nathan Sanchiz-Viel	NPM3D	nathan.sanchiz-viel@mines-paristech.fr
Sergi Sánchez	I2CAT	sergi.sanchez@i2cat.net
Nuria Trujillo	HSP	ntrujillo@hispasat.es
Spyros Papafragkos	ATC	a.papafragkos@atc.gr
Francisco Vázquez	I2CAT	francisco.vazquez@i2cat.net

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1

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Table of Contents

LIST OF TABLES	6
LIST OF FIGURES	7
Acronyms and Abbreviations	9
Executive Summary	12
1 Introduction	13
1.1 Purpose of the document	13
1.2 Methodology	13
1.3 Structure of the document	14
2 Hardware Components	14
2.1 High Level Functional Architecture of the Use Cases	14
2.2 On-Board Hardware Components for Communications	15
2.2.1 3.5GHz 5G NR Radio Access Unit	15
2.2.2 IEEE 802.11ad 70 GHz access network on-board units	16
2.2.3 Satellite Radio Access Unit	17
2.2.4 ACS-GW	24
2.2.5 TCN switches	27
2.3 Service-Specific Hardware Components	31
2.3.1 Hardware Components On-Board the Train	31
2.3.2 MEC Layer Compute Requirements	36
2.3.3 Cloud Layer Compute Requirements	39
3 Software Components	40
3.1 Service-Specific Software Components	42
3.1.1 UC3 FRMCS – P1: Advanced Sensor Monitoring on Board	42
3.1.2 UC3 FRMCS – P2: Obstacle Detection	46
3.1.3 UC3 FRMCS – P3: Passenger Safety and Comfort	53
3.1.4 UC3 – Business 1: High-Quality Wi-Fi to Passengers	60
3.1.5 UC3 – Business 2: Multi-tenant Mobile Service for Passengers	60
3.2 Common Software Components	61



3.2.1	ACS-GW On-Board the Train	61
3.2.2	Geolocation module	63
4	Conclusion	67
5	References	68
	Annex 1 – Details on the TGV	70
	Annex 2 – Details on LFP Train	72
	Annex 3 – LIDAR datasheet	73

LIST OF TABLES

Table 1 - Satellite antenna connectors	22
Table 2 - Satellite antenna characteristics	23
Table 3 - Satellite modem characteristics.....	24
Table 4 – Technical characteristics CloudEngine S5735-L24P4X-A1.....	29
Table 5 - Technical characteristics of CloudEngine S5736-S24UM4XC.....	30
Table 6 - Access point technical features.....	35
Table 7 - Small-cell specifications	35
Table 8 - Data analytics module requirement	37

LIST OF FIGURES

Figure 1 - High-level functional architecture of UC3 and UC4 in the railway scenario (extracted from D5.1 [2])	14
Figure 2 - 5G modem and adaptor.....	15
Figure 3 - Block diagram of the train node	16
Figure 4 - Satellite on-board components	17
Figure 5 - Satellite configuration diagram	19
Figure 6 - SOTM Ka railway terminal	20
Figure 7 - Satellite modem HT2500 [5]	24
Figure 8 - SuperChief motherboard	25
Figure 9 - network interface card	26
Figure 10 - NICs on SuperChief motherboard.....	26
Figure 11 – SuperChief casing.....	27
Figure 12 – Ethernet Network Architecture TCN.....	28
Figure 13 – Front ports and back view of S5735-L24P4X-Aa switch, taken from the Huawei brochure	29
Figure 14 – Front ports and back view of S5736-S24UM4XC switch (taken from a Huawei brochure).....	30
Figure 15 - Photograph of the LiDAR inside the TGV cockpit during the experiments.....	32
Figure 16 - Picture and dimensions of the selected Hikvision PTZ camera. Source: [9].....	33
Figure 17 - Hikvision graphical user interface to view and operate the PTZ camera. Source: [10].....	34
Figure 18 - Interconnection models between train small cell and core networks	36
Figure 19 - PC housing (BQT BGW37 - PURE BASE 500DX Black): 232 x 443 x 450 (Width, Height, Depth) in mm	37
Figure 20 - Schema of the information flow for the obstacle detection system-based AI with LiDAR. The solid arrows indicate the physical connectivity data flow, and the dashed arrows indicate the wireless connectivity data flow. The red texts indicate the connectivity type, and the green texts indicate the transmitted data type.	39
Figure 21 - Example of internal view of functional blocks showing interfaces.....	40
Figure 22 – UC3 FRMCS Performance Services Blocks (extracted from D5.1 [2])	41
Figure 23 - Behavioural view for FRMCS P1 Advanced Sensor Monitoring on Board (extracted from D5.1 [2])	42
Figure 24 - UC3 - P1 internal view.....	43
Figure 25 - Behavioural view for FRMCS P2 Obstacle Detection from D5.1 [2]	47
Figure 26 - UC3 P2 internal view.....	47
Figure 27 - Interfaces between two P2 AI modules.....	52
Figure 28 – One of the behavioural view for FRMCS P3 Passenger safety and comfort from D5.1 [2].....	53
Figure 29 - UC3 P3 internal view.....	54
Figure 30 - Interfaces between two P3 AI Modules.....	59
Figure 31 - SuperChief module diagram	61
Figure 32 – ACS-GW and e-BPF	63
Figure 33 - Geolocation module internal view	64
Figure 34 - picture of the TGV that is planned to be used for large scale trial.....	70



Figure 35 - Characteristics of the TGV that is planned to be used for large scale trial.....	71
Figure 36 - GNSS and cellular MIMO2x2 antenna	71
Figure 37 - MIMO 2x2 cellular antenna	71
Figure 38 - LFP Train height	72
Figure 39 - LFP train length	72



Acronyms and Abbreviations

Term	Description
3GPP	3rd Generation Partnership Project
5G	Fifth generation of broadband cellular network technology
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
BPF	Berkeley Packet Filter
CCTV	Closed-Circuit Television
CPRI	Common Public Radio Interface
DS	Differentiated services
EBPF	Extended BPF
EU	European Union
FPA	Flat Panel Antenna
FRMCS	Future Railway Mobile Communication System
GA	Grant Agreement
GHz	Giga Hertz
GUI	Graphical User Interface
HTTP	Hyper-Text Transfer Protocol
HW	Hardware
ICMP	Internet Control Message Protocol
ICT	Information and Communications Technology
IM	Infrastructure Managers
IP	Internet Protocol
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
K _u band	The portion of the electromagnetic spectrum from 12 to 18 GHz

LAN	Local Area Network
LiDAR	Laser imaging Detection And Ranging
MIMO	Multiple-Input and Multiple-Output
mmWave	Millimetre Wave, the portion of the electromagnetic spectrum from 30 to 300 GHz
MNO	Mobile Network Operator
MQTT	Message Queuing Telemetry Transport
NIC	Network Interface Card
NFV	Network Functions Virtualisation
NPU	Network Processing Unit
NR	New Radio
NSA	Non Standalone
NUC	Next Unit Computing
OLE	Overhead-Line-Electrification (for Railways)
OS	Operating System
PoE	Power over Ethernet
PC	Personal Computer
PSU	Power Supply Unit
QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RAN	Radio Access Network
REST	Representational State Transfer
RTSP	Real Time Streaming Protocol
S1	Interface between RAN Node and Core Network
SATCOM	Satellite communication
SW	Software
TCN	Train Communication Network
TCP	Transmission Control Protocol



TCU	Telecommunications Unit
TN	Train Node
UC	Use Case
UE	User Equipment
V2X	Vehicle-to-everything
VM	Virtual machine
VNF	Virtual Network Function
VoIP	Voice over IP
WP	Work Package

Executive Summary

This deliverable D5.2 is the output of the work led in WP5 phase A (Detailed definition of the hardware and software train components required to support UC3 and UC4 in the railway environment). The information presented in this document is based on the work performed in D2.1 [1], which provides an initial definition of the 5GMED use cases, and D5.1 [2], which describes the functional blocks and service components of UC3 and UC4 in the railway scenario, the requirements from the analysis of the use cases definitions, and the basic procedures the service components must satisfy.

The aim of this document is to ensure a proper integration of the hardware components on board the train and the software components deployed on board, in the MEC or in the cloud layers. With this respect, the first part of the document focuses on the mechanical and electrical details of each hardware component that needs to be installed as well as specific integration constraints (e.g., the two 70GHz antennas shall be placed on the roof and at the front and the rear of the train). This first part is split into communication-oriented hardware and hardware supporting the use cases.

The second part of this document is devoted to identify the software components that must be developed to support the uses cases, and especially the interfaces needed in between them. The first subsection focuses on software components supporting services, their internal interfaces, that is how they interact inside a functional block; and their external interfaces, that are required in between different functional blocks. The second subsection describe the common software components among all services developed to support the use cases.

The content of this deliverable is aligned with WP3 work, in particular with D3.2, which provides the planned architecture of the network, including multi-connectivity aspects, service orchestration and slicing. This third release of D5.2 is in line with the latest hardware and software components to be made available to proceed with the tests. Subsequent phases of WP5 tasks, namely Phase B (integration and validation in the small-scale testbed) and Phase C (integration and validation in the large-scale testbed) will use this D5.2 detailed description to conform their content. In a complementary way, this document can be helpful for other tasks in other WPs, such as Task 6.1 (Test case definitions) and Task 7.1 (Cross-border corridor cost/benefit analysis), even if these tasks do not have D5.2 as an input in the WP description of the Grant Agreement.

1 Introduction

1.1 Purpose of the document

The main purpose of this document is to describe all the hardware and software components, including their detailed functionalities and interfaces, required to implement the following 5GMED Use Cases (UC) in the railway scenario, according to the functional architecture and requirements defined in D5.1.

- FRMCS (*Future Railway Mobile Communication System*) [3] applications and business service continuity (UC3), which is intended to demonstrate some challenging FRMCS performance and business applications, ensuring the service continuity in a high-speed train.
- Follow-Me Entertainment (UC4)², which provides the train passengers with media-based entertainment activities (e.g., access to high- quality media contents) ensuring the service continuity while travellers are on the move.

Furthermore, the document identifies which of the hardware and software components are already available and which ones are being developed within the project timeframe.

This document does not distinguish between the small-scale and the large-scale testbed because the essential difference between both deployments is the type of train used: the small-scale testbed is deployed with a LFP maintenance train, and the large-scale testbed is deployed with a SNCF TGV. The components on the ground are the same. The testbed-specific details will be included in D5.3 for the small-scale testbed, and D5.4 for the large-scale testbed.

1.2 Methodology

Starting from D5.1, which provides the functional architecture and the functional and non-functional requirements of UC3 and UC4, this document provides a detailed description of the functionalities and interfaces all the hardware and software components required for both use cases.

First, each partner described the hardware and the software it is responsible for. A lot of detail is required for the hardware part, because much information is necessary to determine how this hardware will be installed in the train. A railway environment has many constraints (power, weight, size, fastening system, location...), and it is needed to address them. For the software part, the services components are deeply described, much more than in D5.1.

Then, as different services components from the same Use Case are developed by different partners, the interfaces between the components need to be defined. So, each partner responsible for a service component had to identify the other partners it has interface with, and they had to agree on a common interface specification.

² This UC4 is not railways specific but covers both transport modes in the 5GMED corridor: automotive and railway.

1.3 Structure of the document

The rest of this document is organized as follows. Section 2 is focused on the hardware on-board the train. It includes a description of the communication devices and of the hardware supporting the service components on-board. Section 3 describes each of the software components, explaining also how the component will be integrated and interfaced with the rest of the software components. Finally, Section 4 completes the document describing the main conclusions in relation with the deliverable objective.

2 Hardware Components

2.1 High Level Functional Architecture of the Use Cases

The high-level functional architecture of UC3 and UC4 in the railway scenario is composed of functional blocks that are included in the Cloud Layer, MEC Layer, and on board the train. Figure 1 (extracted from D5.1 [2]) shows the functional blocks in their respective layer.

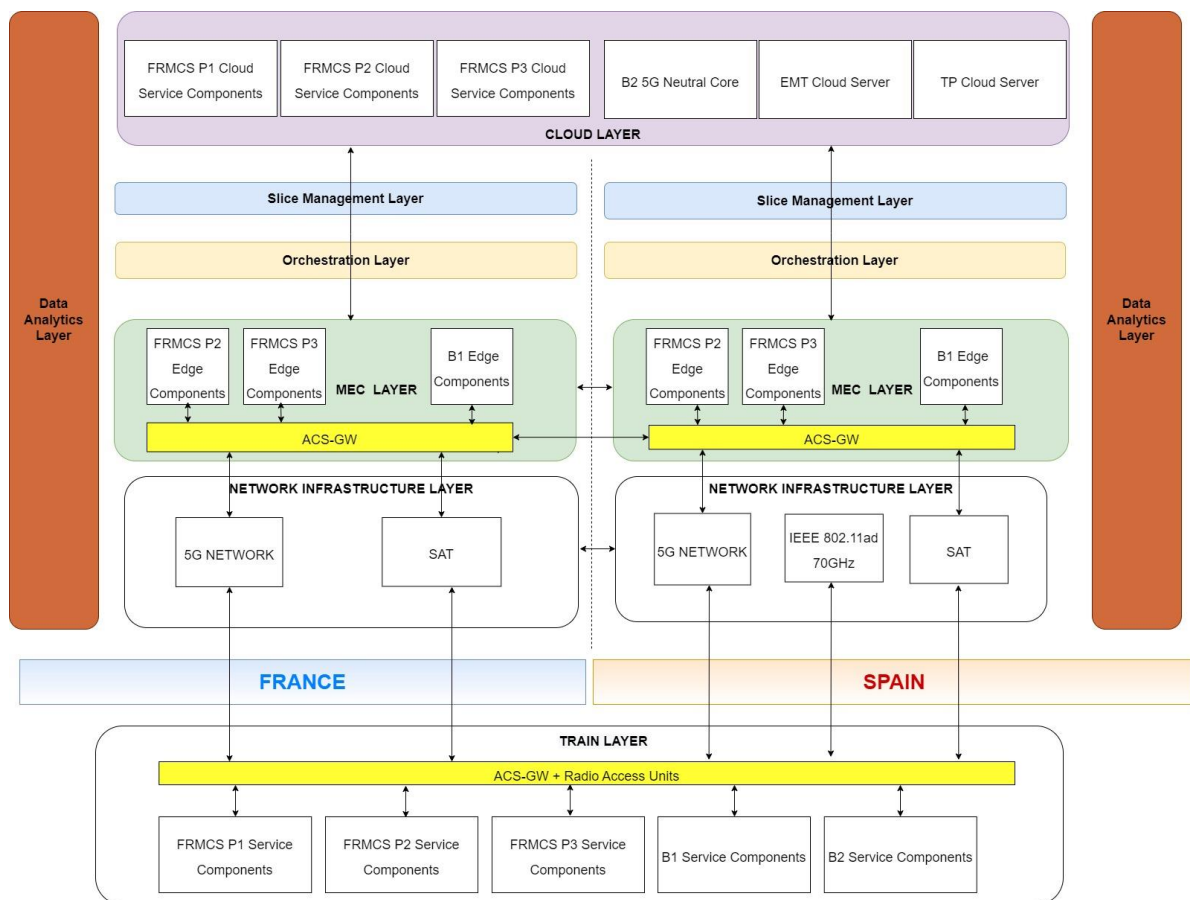


Figure 1 - High-level functional architecture of UC3 and UC4 in the railway scenario (extracted from D5.1 [2])

The hardware components on board the train required to provide connectivity with the ground are described in Section 2.2. These hardware components are part of the common communication infrastructure on board supporting all the services components of UC3 and UC4.

The service-specific hardware components required to support the functional blocks of UC3 are presented in Sections 2.3.1, 2.3.2 and 2.3.3, which respectively describe the features of the hardware components on board, the compute requirements of the UC3 services at the MEC Layer, and the compute requirements of the UC3 and UC4 services at the Cloud Layer.

2.2 On-Board Hardware Components for Communications

This section describes the hardware components on board required to provide connectivity between the train and the ground network infrastructure. These on-board hardware components for communications are:

- The radio access units for 5G NR, IEEE 802.11ad 70 GHz, and satellite communications described in Section 2.2.1, Section 2.2.2 and Section 2.2.3, respectively.
- The train Adaptive Communication System-Gateways (ACS-GW) described in Section 2.2.4.
- The Train Control Network (TCN) switches described in Section 2.2.5.

2.2.1 3.5GHz 5G NR Radio Access Unit

The 5G NR connectivity in the train will be provided by a Quectel RM500Q-GL 5G modem. It supports several bands including the N77 (3.7GHz) and N78 (3.5GHz) bands that will be used in 5GMED for the railway’s scenario.

Both SA and NSA modes are supported, with a data rate that can reach 2.1 Gbps in downlink and 900 Mbps in uplink, as specified in its data sheet. It supports 4x4 or 2x2 MIMO configuration.



Figure 2



Figure 2 - 5G modem and adaptor.

The modem is installed inside an adaptor as shown in Figure 2. The adaptor provides an SMA connector to connect the antenna and USB connector to connect to a computer. The computer that will be used is an Intel NUC. It is connected to the modem through a USB cable, and to the TCN through an RJ45 10Gb Ethernet interface. Its purpose is only to forward data packets between the modem and the ACS-GW through the TCN. The components and their locations in the train are shown in D5.1 [2].

2.2.2 IEEE 802.11ad 70 GHz access network on-board units

Two units, located at both ends of the train are the components charged to establish the connection with the on-ground units located in the trackside poles.

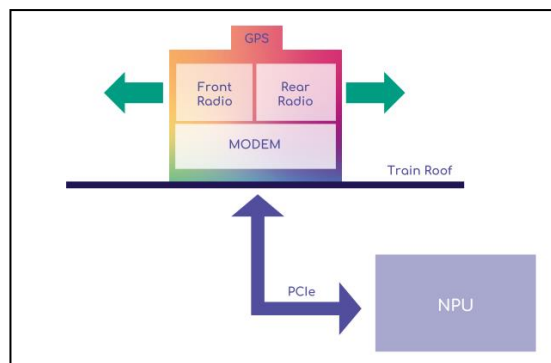


Figure 3 - Block diagram of the train node

Each on-board unit is made up of the following blocks, described in Figure 3

- Modem: The modem is located between the NPU and the radio. This is the unit that contains the MAC & PHY that converts digital data to / from analogue signals that the radio uses to modulate / demodulate the carrier.
- Network Processing Unit (NPU): Gives access to the on-board train network and is connected to the TCN.
- mmWave RADIOS (front and rear): The mmWave radios convert the radio analytic signals to and from the carrier and is controlled by the NPU. The beams of the train and trackside antennas are aligned automatically.
- A GPS unit, that will be used by the Geolocation module to be developed

Each unit has the radio pod mounted on the roof. This contains the modem and two antennas that are 180 degrees to each other to provide forward and reverse coverage. The NPU (Network Processor Unit) is a separate unit that is mounted inside the train in the roof attic near the radio pod, and the two units are connected via a PCIe link.

Both NPUs will be connected to the aggregation appliance box inside the train.

An aggregation appliance establishes multiple data-streams across available mmWave links to provide increased throughput and ensure link redundancy and resilience. Note that all the connections are based on 10G Ethernet ports (except the PCIe link between the NPUs and the antennas on the roof).

2.2.3 Satellite Radio Access Unit

2.2.3.1 Satellite outdoor/indoor components

For the train on-board infrastructure in the satellite network, two main devices will be required, the satellite antenna and satellite modem. The main components of the satellite equipment are:

1. Satellite antenna
2. Control Unity for the antenna
3. Satellite modem

Moreover, RF cables and ethernet cables are also needed (see section 2.2.3.5), as well as M&C and power supply.

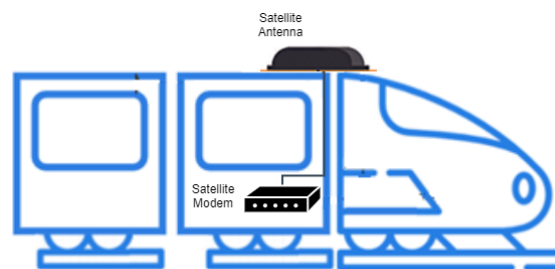


Figure 4 - Satellite on-board components

Figure 4 is a very simplified view of main components location in train. Here are more details about them:

Satellite antenna: the terminal includes a low-profile moving antenna for two-way satellite communications, suitable for installation on any train. It allows to receive and transmit satellite on the move (SOTM) communications streams. It includes the receive and transmit panel and electronic circuitry and is designed, built and ruggedised for outdoor operations.

Satellite modem: A SATCOM modem which should be located in a rack inside the train, connected to the satellite antenna and the TCN, that will be connected to the QoS Gateway. A satellite modem is employed to set up data transfers using a communications satellite to rebroadcast the information. The main function for a satellite modem is to convert an input bitstream to a radio signal and vice versa.

2.2.3.2 Technical specifications

The satellite connections consist of the externally mounted antenna over the train roof and the internal modem as a rack unit:

**External satellite antenna: SOTM Ka Railway Antenna³**

RF connection to modem (max 20m)

In-train Power Supply

GPS location

Management connection

Internal modem: HT2500 Satellite Router⁴ [5]

RF connection to antenna (max 20m)

Data connection to central switch (Ethernet, RJ-45)

Power supply

Management USB connection

The complete system diagram and connections are represented in Figure 5:

³ Although this component is the candidate now, it is still pending of confirmation

⁴ Although this component is the candidate now, it is still pending of confirmation

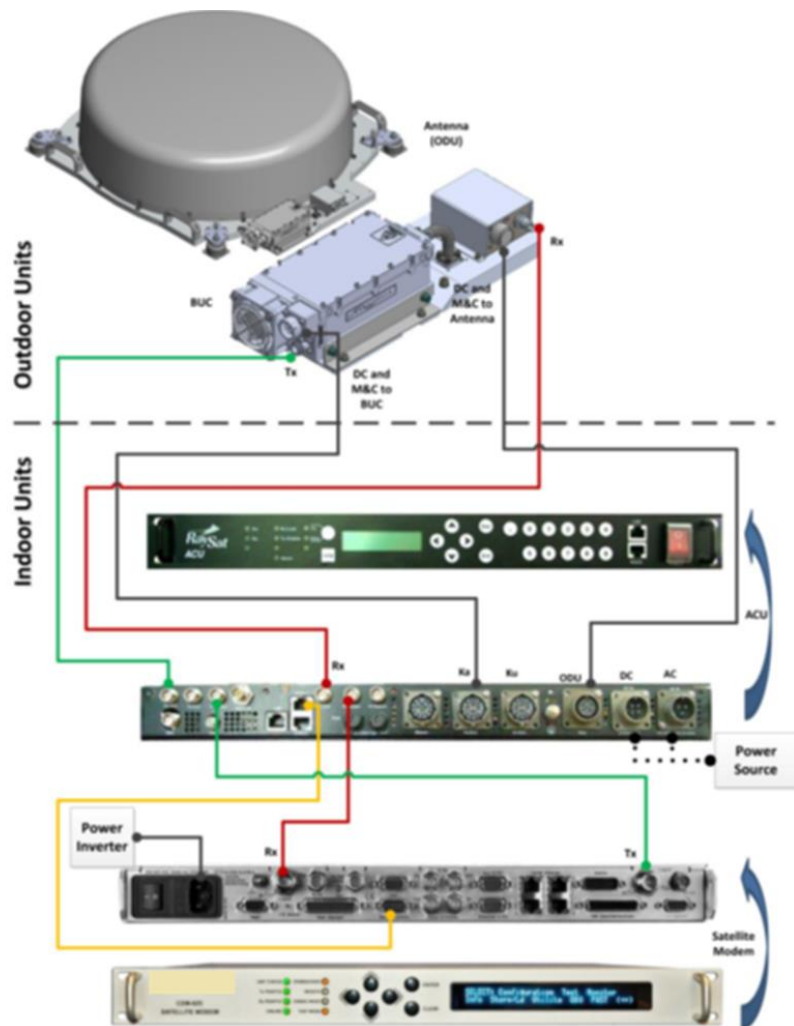


Figure 5 - Satellite configuration diagram

2.2.3.3 Antenna

The antenna selected for being mounted over the train is based on low-profile technology with electronic circular polarization switching (RHCP or LHCP), ensuring the highest performance while providing a small impact on the mounting over the train. It is a mechanically self-supporting Ka-band array antenna. The GPS reception together with tracking algorithms allow the Antenna Control System to continuously track and point the required satellite.

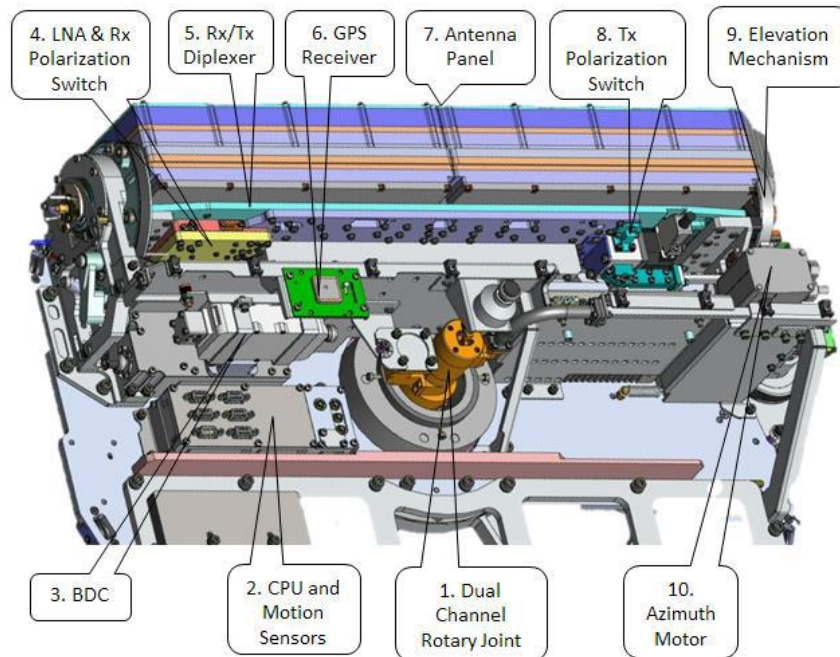
The antenna is compatible with commercial Ka-band uplink frequencies (29.0 to 31.0 GHz).

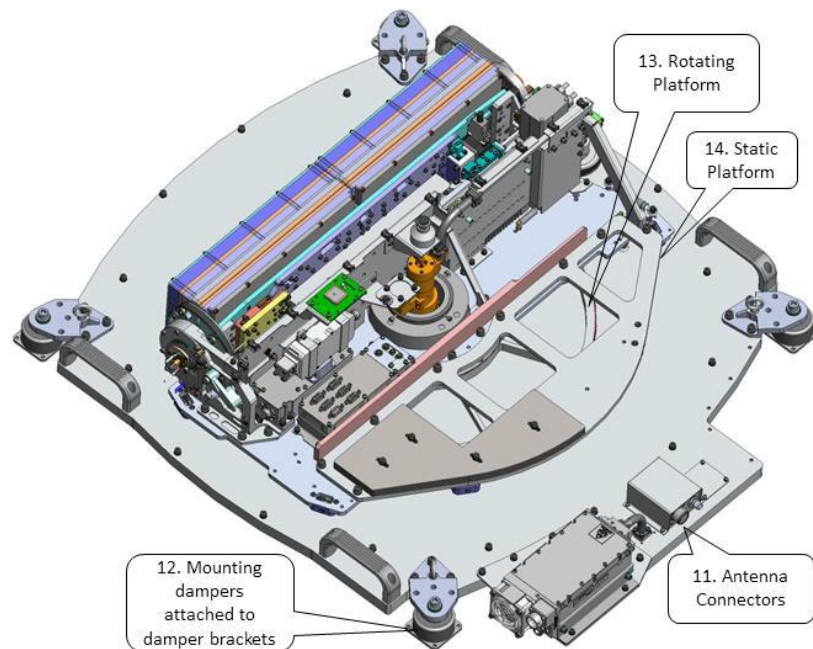


Figure 6 - SOTM Ka railway terminal

The satellite antenna (Figure 6) is based on an external terminal with a protection radome and an internal Power Supply Unit (PSU).

This figure shows the main components of the antenna:

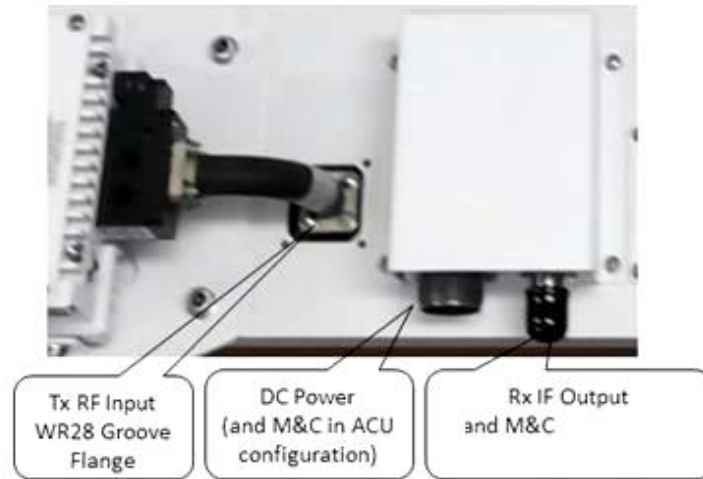




Principal technical specifications are:

1. **CPU and motion sensors:** It automatically controls the antenna terminal. They ensure tracking under normal conditions and maintain the orientation of the antenna towards the satellite for some period when the satellite signal is not available (during lockouts).
2. **BDC:** It converts Ka-band (Rx) receive signal frequencies (19.2 – 21.2 GHz) to the IF band (1000 – 2000 MHz). Like a LNB.
3. **LNA and Rx polarisation switch:** Low-noise amplifier used for amplification of the input signal with minimal noise and distortion. Allows RHCP or LHCP polarisations to be passed through the LNB.
4. **GPS receiver:** Gives the geographical location of the antenna. The elevation angle is based on its readings and the longitude of the target satellite.
5. **Antenna panel:** The antenna panel consists of the array panel and the waveguide combiner components. The array panel uses modern flat antenna technology which allows broadband operation and covers the following frequency ranges:
 - Receive frequency range: 20.2 - 21.2 GHz or 19.2 - 20.2 GHz
 - Transmit frequency range: 30.0 – 31.0 GHz or 29.0 – 30.0 GHz
6. **Elevation mechanism:** Positions the panel at the appropriate elevation angle by means of a stepper motor. An elevation sensor is used to define the initial position of the panel.
7. **Connectors:** Antenna interface connectors:
 - Tx IF input WR28 Slot flange.

- TNC-Female Rx IF output, and M&C in MLT1000 configuration.
- DC power from DC power supply and M&C from ACU.



Note: The BUC should be installed next to the antenna.

- 8. Mounting dampers attached to damper brackets:** Shock absorbing devices placed between the static antenna plate and the mounting plate, which dampen the antenna from vibrations and shocks. The dampers are made of stainless steel.
- 9. Rotating Platform:** It contains all the antenna parts and is fixed to the static platform by means of a central bearing and peripheral damping rollers.
- 10. Static Platform:** Base of the entire antenna supporting the turntable, a top cover radome, a connector box and four mounting shock absorbers.
- 11. Radome:** Antenna top cover manufactured to be RF transparent, ensuring sufficient mechanical and weather protection of the antenna panel and all turntable components. It is attached to the static platform and provides additional rigidity to the entire antenna.

Connector	Description	Observations
J1 Tx	Coaxial Connector Panel	IF TX (from modem to BUC)
J2 Rx	Coaxial Connector Panel	IF RX (from antenna to modem)
J3 M&C to antenna	DC pwr + M&C MLT1000	PWR connector and comm
J4 M&C to BUC	Amphenol #360011 + CIR030FP-20A-9P-F80-20	PWR connector and comm

Table 1 - Satellite antenna connectors

The connections of the antenna include:

- Coaxial connector for the RF TX-RX with the modem.

- Monitoring and control connections.
- Power connection (Amphenol Serie 36001).
- GPS connection.

The most relevant radio, physical and power characteristics of the antenna are as follows.

Parameter	SOTM KA
Frequency band	RX: 19.2 GHz – 21.2 GHz TX: 29.0 GHz – 31.0 GHz
Polarization	Circular (LHCP or RHCP)
Dimensions	Terminal: LxDxH 838 x 959 x 254 mm (roof of the train) PSU: LxDxH 278 x 543.5 x 112.1mm (inside the train)
PSU Weight	Satcom terminal: 49.7Kg (additional to baseplate) PSU: 10Kg
Antenna power consumption	120 W
Input voltage	220 VAC
Environmental & EMI/EMC	EN50155

Table 2 - Satellite antenna characteristics

The antenna can be mounted directly over the train roof or with a customized baseplate, that will be confirmed based on the final train model. The installation shall be done over a horizontal surface over the train roof.

2.2.3.4 Antenna Power Supply

Finally, the power supply of the antenna is placed inside the train, with a power connection towards the antenna. The unit also includes a Monitoring and Control (M&C) connection and an additional power connection for a modem.

2.2.3.5 Modem

For the internal assembly, the modem for satellite communications (Figure 7) shall be located as close as possible to the antenna (shortest RF cable path possible). The modem incorporates the RF connection to the antenna, power supply connection and the networking interfaces (RJ-45) for the communication with the central switch and management interface.

The Hughes HT2500 is a high-performance satellite router designed to be installed in a suitable standard 19" equipment rack.

The compact design consumes only one rack unit (1U rackmount) and supports a variety of power options. The terminal supports dual-wire IFL which allows the use of a standard L-band interface to the outdoor unit, as well as operation over a wide range of operating frequencies with a variety of high-power BUCs. In addition, the HT2500 comes equipped with 4 GigE LAN ports.



Figure 7 - Satellite modem HT2500 [5]

The most relevant modem characteristics are represented in the next table (Table 3):

Parameter	HT2500 Satellite Router
Size	482,6mm (w) x 266,7mm (d) x 44,45mm (h)
Weight	3.72 kg
Temperature (operating)	-0°C to +50°C
Humidity (operating)	Max 77% (noncondensing)
Input Voltage	90-264 VAC
Data Interface	4 GigE LAN Ports
Management Interface	USB port
Regulatory Compliant	Safety: UL/CSA/EN 60950-1 EMC: FCC Part 15 class B, ICES-003 RoHS-2 compliant
Estimated maximum power consumption	≈120W

Table 3 - Satellite modem characteristics

2.2.4 ACS-GW

The **ACS-GW** is a module deployed on board for aggregating/disaggregating the application traffic and enforcing the correct forwarding policy depending on the per-application required performance KPIs and the current network QoS. The ACS-GW is logically placed in between the end user devices (mobile phones, cameras, laptops, etc.) and the radio access units in charge traffic transmission to/from ground.

In order to minimize the configuration/deployment effort and the space required to host the physical components, the above-mentioned module will be implemented on a Linux server named **SuperChief** (see next section).

The **ACS-GW** will be implemented on a virtual machine. A physical NIC will be dedicated to the VM through a PCI passthrough (NIC2).

The **SuperChief** consists of the following main HW components:

- A SuperMicro motherboard
- 3 Ethernet Network interface cards (NICs)
- Case
- Power Supply
- Cables

Motherboard

The Linux server will be developed through a motherboard of the Supermicro family. This motherboard (Figure 8) is optimized for high-performance computing platforms. It supports 1st and 2nd Gen Intel® Xeon® Scalable Processors with up to 28 cores and a thermal design power of up to 205W.

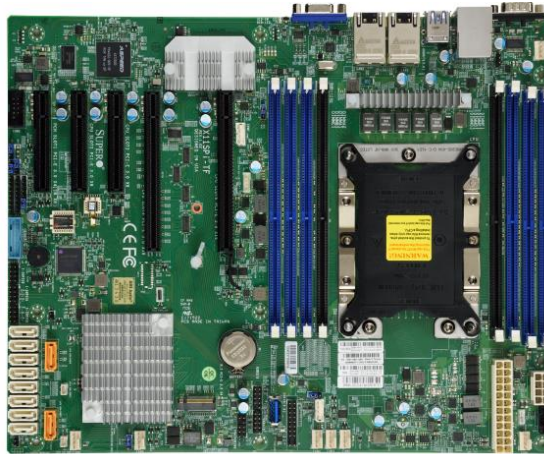


Figure 8 - SuperChief motherboard⁵

Network Interface Card

SuperChief is equipped with three Network Interface Cards (NICs) that have different purposes.

The NIC2 and NIC3 belong to the Intel NIC family and are 10 Gigabit Ethernet (GbE) server network cards that meet the demanding needs of the next generation datacentre. By providing unmatched features for server and network virtualization, small packet performance, and low power. The Intel NIC is composed of two SFP+ 10GBase-SR/LR with an available speed of 10 Gbps in full-duplex mode (Figure 9).

⁵ <https://www.supermicro.com/manuals/motherboard/C620/MNL-1900.pdf>



Figure 9 - network interface card⁶

The Power Requirements is 6.2 W Maximum @ +3.3 V and the NIC will be connected at the host via a Bus Connector PCI Express 2.0. The **NIC2** will be interfaced to the VMs with PCI passthrough connection which allow VMs to have exclusive access to PCI devices for a range of tasks and allows PCI devices to appear and behave as if they were physically attached to the guest operating system. **NIC3** will not be used and will serve as a spare interface.

Unlike **NIC3** and **NIC2**, **NIC1** is a LAN interface located on the I/O back panel, pointed by “1” in Figure 10 of the supermicro motherboard which supports communication speeds between 1Gbs / 10Gbs connected directly to the processor on the motherboard. This interface can provide to the external world, remotely connected to the VPN installed on **SuperChief**, a configuration/control interface to all components connected to the TCN network, the connection can be made through ethernet cables. This interface is to be used only in case of errors, malfunctions or misconfiguration in the ACS-GW to access the SuperChief server through a VPN provided by the LTE router.

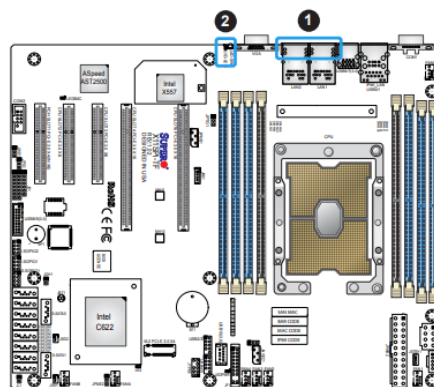


Figure 10 - NICs on SuperChief motherboard⁷

NIC1 and NIC2 will be connected to the TCN network present on the train.

⁶ <https://www.priceblaze.com/x520-da2.html>

⁷ <https://www.supermicro.com/manuals/motherboard/C620/MNL-1900.pdf>

Case

All the components listed above will be assembled in a gaming case. The case we will use for our **SuperChief** server will be the NZXT H510. The dimensions of the case are ⁸ 460x210x428 (width x depth x height) and weighs 6.6 kg .

Looking at Figure 11 we can see that it consists of two sections, the upper section is used to allocate the motherboard with the Network Interface Cards, while the one below is used to allocate the power supply and the SSD memories.



Figure 11 – SuperChief casing⁹

2.2.5 TCN switches

The TCN (Train Communication Network, not compliant with TCN from EN61375 [7]) is a backbone supporting communication between all components. This backbone is a layer 2 network made of switches connected with each other with optical fibre. It acts transparently towards the applications.

The TCN Ethernet network is composed of three switches joined by a 10G fibre optic link. Two units use the Huawei model S5735-L24P4X-A1 and will be located in each cabin of the TGV train (more precisely, in the immediate coaches adjacent to these ones): The third switch is the Huawei model S5736-S24UM4XC close to the Bar Coach in the middle of the train. In the LFP maintenance train, all the switches will be collocated in the unique vehicle the train has, but their topology will be maintained, as it shown in Figure 12.

⁸ Case specifications copied from: <https://nzxt.com/product/h510>

⁹ <https://nzxt.com/product/h510>

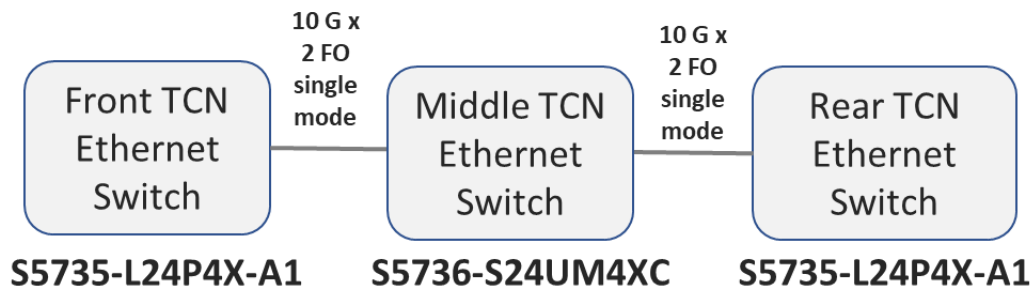


Figure 12 – Ethernet Network Architecture TCN

The rest of the 10G ports available will be used for the Ethernet connection of the devices that use a higher data flow, such as:

- One 10G for 802.11 ad 70GHz unit into Cabin 1
- One 10G for 802.11 ad 70GHz unit into Cabin 2
- One 10G for ACS-GW into Bar Coach
- One 10G for 802.11 ad 70GHz Aggregation Box into Bar Coach
- One 10G for B1 Train Traffic Generator into Bar Coach

10G connections will be made using single-mode or multi-mode SFP+ optical transceivers depending on the type of fibre that will be chosen

2.2.5.1 CloudEngine S5735-L24P4X-A1 Switch description

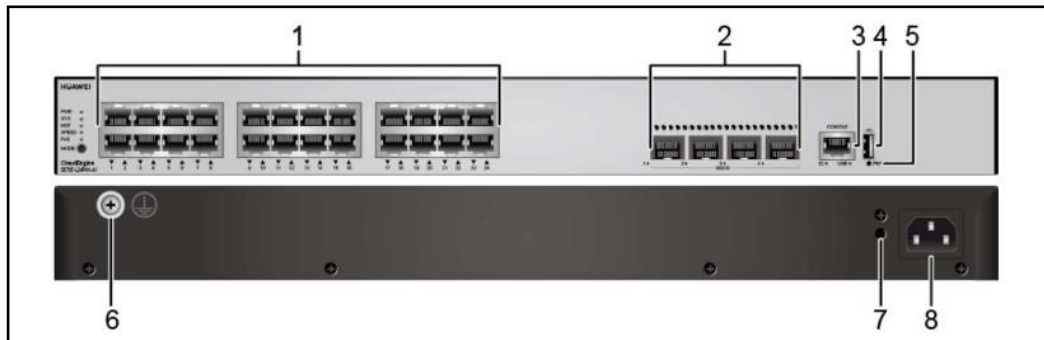
The Switch S5735-L24P4X-A1 belongs to the CloudEngine S5735-L Huawei series and its characteristics are described in Table 4.

Product Model	CloudEngine S5735-L24P4X-A1
Forwarding Performance	96 Mpps (refers to communication between two switch ports, in millions of packets per second)
Switching Capacity	128 Gbit/s per switch / 336 Gbit total TCN
Fixed Ports	24 x 10/100/1000Base-T ports
	4 x 10 GE SFP+
PoE+	Supported
MAC Features	MAC address auto-learning and aging Static, dynamic, and blackhole MAC address entries Packet filtering based on source MAC addresses Interface-based MAC address learning limiting
VLAN Features	4094 VLANs Guest VLAN, Voice VLAN GVRP MUX VLAN

	VLAN assignment based on MAC addresses, protocols, IP subnets, policies, and ports 1:1 and N:1 VLAN mapping
--	--

Table 4 – Technical characteristics CloudEngine S5735-L24P4X-A1

In the Figure 13 we have a view of the front and back of the switch CloudEngine S5735-L24P4X-A1 with the distribution of all the connections.



1	24 x 10/100/1000BASE-T PoE+ ports	2	Four 10GE SFP+ ports
3	One console port	4	One USB port
5	One PNP button	6	Ground screw
7	Jack for AC power cable locking strap	8	AC socket

Figure 13 – Front ports and back view of S5735-L24P4X-Aa switch, taken from the Huawei brochure

2.2.5.2 CloudEngine S5736-S24UM4XC Switch description

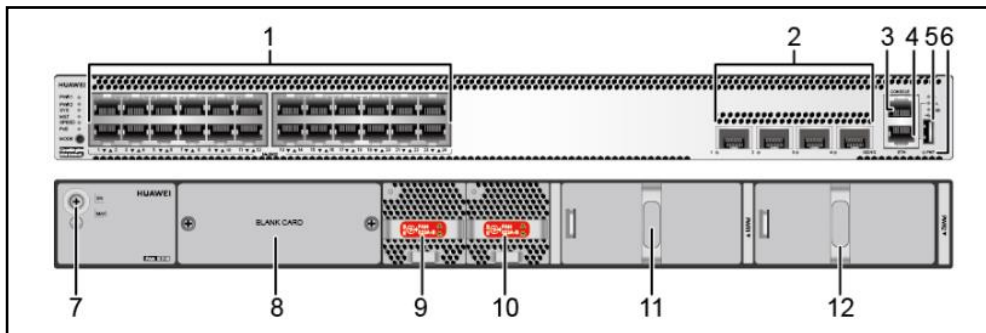
The Switch S5736-S24UM4XC belongs to the CloudEngine S5736-S Series Multi-GE Switches of Huawei and its characteristics are described in Table 5 (switching capabilities). The number of available 10G SFP+ ports has been expanded by eight by adding the S7X08000 subcard.

Product Model	CloudEngine S5736-S24UM4XC
Forwarding Performance	480 Mbps (refers to communication between two switch ports, in millions of packets per second)
Switching Capacity	880 Gbps / 2.72 Tbps
Fixed Ports	24 x 100M/1G/2.5G/5G/10G Base-T Ethernet ports 4 x 10 GE SFP+ ports
Subcard S7X08000 Ports	8 x 10GE SFP+ ports
PoE+	Supported
MAC Features	MAC address auto-learning and aging Static, dynamic, and blackhole MAC address entries Packet filtering based on source MAC addresses Interface-based MAC address learning limiting
VLAN Features	4094 VLANs Guest VLAN, Voice VLAN GVRP

	<p>MUX VLAN VLAN assignment based on MAC addresses, protocols, IP subnets, policies, and ports 1:1 and N:1 VLAN mapping</p>
--	--

Table 5 - Technical characteristics of CloudEngine S5736-S24UM4XC

In the Figure 14 we have a view of the front and back of the switch CloudEngine S5736-S24UM4XC with the distribution of all the connections.



1	24 x 100M/1GE/2.5GE/5GE/10GE BASE-T PoE++ ports (multi-GE ports)	2	Four 10GE SFP+ optical ports
3	One console port	4	One ETH management port
5	One USB port	6	One PNP button
7	Ground screw	8	Rear card slot equipped with S7X08000 subcard with 8-Port 10GE SFP+
9	Fan module slot 1	10	Fan module slot 2 (empty)
11	Power module slot 1: PAC1000S56-DB, 1000W AC Power Module	12	Power module slot 2 (empty)

Figure 14 – Front ports and back view of S5736-S24UM4XC switch (taken from a Huawei brochure)

2.3 Service-Specific Hardware Components

This section describes service-specific hardware components required to support the functional blocks of the railway use cases. Section 2.3.1 describes the features of the hardware components on board for each service of UC3, Section 2.3.2 describes compute requirements of the UC3 services at the MEC Layer, and Section 2.3.3 describes the compute requirements of the UC3 and UC4 services at the Cloud Layer.

2.3.1 Hardware Components On-Board the Train

This section describes the features of the hardware components on board the train for each of the services of UC3.

2.3.1.1 P1: Advanced Sensor Monitoring

To support UC3 FRMCS P1: Advanced Sensor Monitoring (Use Case 3 : FRMCS Performance 1, see [2]), an IoT Traffic Generator, and also an Train Presentation Tool will be implemented in the Train Layer. Their functionalities are explained in Section 3.1.1.

These programs do not need specific or specialized hardware. They will be installed on a laptop in the train. The laptop should have at least one RJ45 connector for Ethernet, and it should consume 43W maximum.

2.3.1.2 P2 LIDAR

We will use in the project a cutting-edge active sensor system, a LiDAR (Light Detection And Ranging), which is able to digitalize space in three dimensions with integrated lasers. By making a large number of distance measurements in a quasi-sphere around the sensor position, a 3D map of the surrounding environment is built. This type of sensor is extremely interesting to use in this project due to the large amount of data which needs to be transmitted to an, generally distant, intelligent system.

The LiDAR which will be used in the project is a Velodyne Puck with 16 lasers (VLP16) – the datasheet is given in Annex 3. This model has a low weight (<1kg) and consumes little power (approximately 8W). The range varies from 0.5 m up to 100 m for a 360° horizontal field of view and a 30° vertical field of view (-15° to +15°).

The LiDAR will be placed in the cabin of the train, preferably on a small tripod for stability. Some experiments were conducted by NPM3D and SNCF inside the cockpit of a TGV (TGV number 4051) to assess the feasibility of the placement and whether the windshield could be an issue for the laser propagation. After an analysis of the results, it seems that the windshield is not a problem for the sensor and that there is enough free field-of-view for scanning. The shows the LiDAR position inside the train cockpit during the experiments.



Figure 15 - Photograph of the LiDAR inside the TGV cockpit during the experiments

Regarding network connection, the LiDAR sends data packets (PCAP format) by UDP (User Datagram Protocol) through an Ethernet cable toward a computer at around 1Mo/s. These raw data need processing before being usable. Efforts have to be taken to transform the initial set of distance measurement (binary values in spherical coordinate system) into a working normalized format (a point cloud in Cartesian coordinate system).

2.3.1.3 Cameras and microphones

A Closed-circuit television (CCTV) camera with a built-in microphone will be used to detect disruptive or tense situations inside the train. More specifically, the audio captured from the camera microphone will be analysed to recognize if anyone inside the train is saying the emergency word “help”.

The model selected is the Hikvision DS-2DE2A404IW-DE3 [9], which is a compact 4 Megapixel camera with pan, tilt and zoom (PTZ) capabilities that will allow the operator in the Cloud Control Centre (CCTV Management Module) to manipulate it remotely. shows a picture of the camera and its dimensions. It has a build-in microphone that can capture audio at a maximum bitrate of 192 kbps. While the recorded audio will be analysed by the P3 AI module (see Section 3.1.3.3) to detect the presence of

an emergency word, the video stream will be used only as a verification and control tool by the CCTV Management Module.

The maximum resolution of the camera is 2560 x 1440 pixels with Wide Dynamic Range capabilities, which will allow for a clear vision of the inside of the train. Regarding the PTZ capabilities, it has a pan movement range of 0° to 355°, a tilt movement range of 0° to 90° and a 4x optical zoom. Although this should be sufficient to cover all the area of the Bar couch, 2 cameras will be used to avoid problems with occlusions and to ensure the quality of the audio recorded throughout the train.

The camera has a 10 M/100 M Ethernet Interface that will be used to connect it to the train switch. It will also power the camera with PoE 802.3af, requiring 36 to 57 VDC, 0.35 A and a maximum of 11.2W.

Real Time Streaming Protocol (RTSP) is the preferred protocol to access the live video and audio stream from the P3 AI module, although the camera accepts a wide variety of protocols that may be considered in future deliverables. In the case of the CCTV Management Module, the operator can log into the camera GUI using a web browser and control it remotely, as shown in . The camera live stream and control can also be shown in the Train Presentation Tool for demonstration purposes.



Figure 16 - Picture and dimensions of the selected Hikvision PTZ camera. Source: [9]

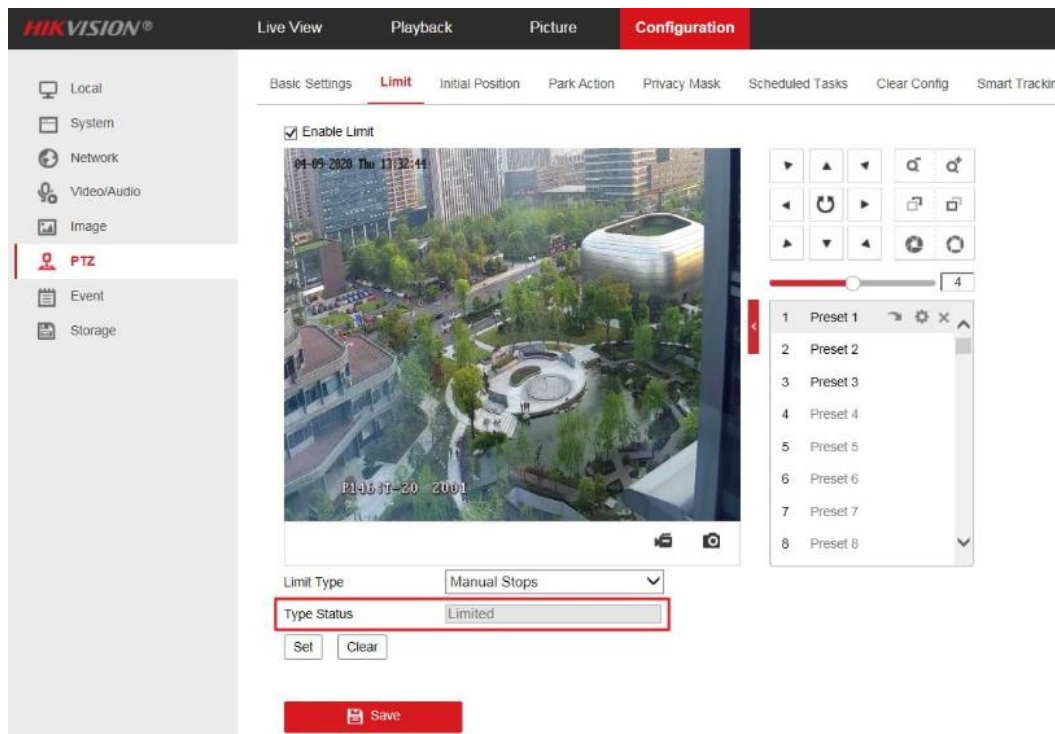


Figure 17 - Hikvision graphical user interface to view and operate the PTZ camera. Source: [10]

2.3.1.4 B1 Wi-Fi AP

The G-AP-IX450 Access Point from Galgus meets the new standards IEEE 802.11ax, known as the standard WiFi6, that implements 2x2 MU-MIMO (2.4 GHz) and 2x2 MU-MIMO (5 GHz). The equipment has an integrated antenna inside, which will facilitate installation on the train with a standard support. The equipment can be powered through a POE+ port of the onboard switch or through a 220 Vac or PoE+ converter.

The main characteristics of the access point G-AP-IX450 from Galgus are described in the next table.

Technical Data	Descriptions
Power average consumption	48v PoE 24W (peaks up to 30W)
Size / Weight	198 x 198 x 41 mm / 750 g.
Temperature / Humidity	Operation: -20°C – 45°C / 5% - 95% (non-condensing)
Standards	IEEE 802.11a/b/g/n/ac/ax
MIMO	2x2 MU-MIMO (2.4 GHz); 2x2 MU-MIMO (5GHz)
Spatial streams	2 per band
Chanel width	20, 40, 80, 160 MHz
PHY rates	Peak: 1800 Mbps; 2.4 GHz: 600 Mbps; 5 GHz: 1200 Mbps
Multi SSID	Up to 24 (12 at 2.4 GHz and 12 at 5 GHz) CONF.
Clients/AP	Up to 256

IP	IPv4 & IPv6, DHCP Client/server, Static and Dynamic IP
Network	IEEE 802.1s, IEEE 802.1d, VLAN tagging (802.1Q), Supports LACP, LLDP
VLAN	Dynamic VLANs, Port forwarding, Segmentation based on VLANs, Tag VLAN based on SSID

Table 6 - Access point technical features

2.3.1.5 B1 Traffic Generator

A Traffic Generator used for B1 service purposes will be an INTEL NUC device (Next Unit of Computing), that support Ethernet 10 Gbps (and enough resources to generate 2Gbps traffic flows) and Wi-Fi 6.

A similar NUC is installed in the MEC Layer and the generated traffic is exchanged between the two PC NUC (see Section 2.3.2.4).

2.3.1.6 Passengers UEs

Passengers UEs will be smartphones from the trial team. The non 5G capable ones will be used for Wi-Fi traffic while the 5G capable ones will be used for the small cell on board.

2.3.1.7 Small cell/Neutral host cell

An indoor small cell with embedded antennas will be connected to the TCN using a dedicate 1Gb ethernet cable.

The small cell will be an Amarisoft callbox Classic. It supports the frequency range FR1 (i.e., 410 MHz – 7125 MHz) including bands n78 and n77-upper, which the bands that will be used for the implementation of the project use case. The most important specifications of the small cell are summarized in the table below.

Technical Data	Descriptions
3GPP release	16
Bandwidth	Up to 50 MHz
MIMO	Up to 4x4 in downlink
Modulation scheme	Up to 256-QAM in DL and UL
Supported modes	NSA, SA
Max number 5G cells	3
Wireless range	10 m

Table 7 - Small-cell specifications

Furthermore, the Amarisoft can be connected to an integrated Amarisoft core or any other external core. It was successfully tested with the Free5GC core that will be used as the neutral operator core network. The Free5GC core was chosen in order to implement the satellite slice with the slice classifiers as proposed; it is required to have a modified SMF, the Druid 5GC could not be used.

In addition to the physical architecture, the use case will need to determine the interconnection model with the core networks on the Spanish and French side as shown in Figure 19.

A UE in the train will be connected to the neutral operator core network that will forward the data of this user to the UE’s core network, whatever is the operator of the UE. This is similar to home routed roaming approach.

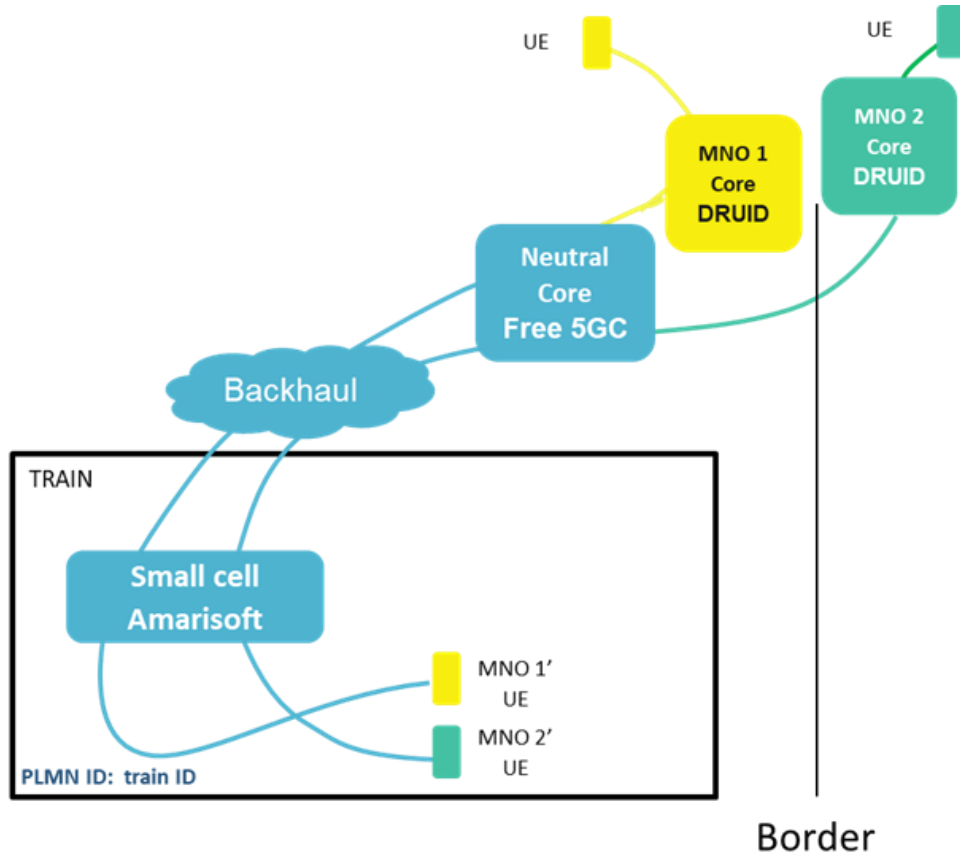


Figure 18 - Interconnection models between train small cell and core networks

The exact interconnection model will be determined based on the network setup defined in WP3.

Finally, an aspect to consider for this use case is the carrier frequency at which the small cell will be configured to operate, and whether this carrier frequency needs to be reconfigured when the train crosses the border.

The physical dimensions of the Small cell are 30 cm × 27 cm × 35 cm, its weight is 11 Kg.

2.3.2 MEC Layer Compute Requirements

This section describes compute requirements imposed by each of the services of UC3 at the MEC Layer.

2.3.2.1 P3 AI Module

A P3 AI Module will be responsible for analysing the live audio stream of the CCTV cameras and detecting if a predefined emergency word is being said inside the train. To this end, a pretrained speech recognition model will be employed to transcribe in real time the speech recorded by the camera microphone. If no emergency word is detected, the video, audio and transcripts will be deleted after a prudential period of time.

The exact speech recognition model to be used is still to be defined. However, there is special attention put in the Vosk toolkit [11] for providing a flexible open-source API with several state-of-the-art models that can recognize speech in multiple languages. For demonstration simplicity, only the English language is currently being considered, although there is an open discussion on the possibility of detecting emergency words in more than one language.

Similar to the P3 Video Storage Module, the P3 AI Module will be located exclusively in the Edge Layer, so there will be no processing requirements inside the train. The requirements for the Edge Server will heavily depend on the number of cameras that are installed within the train and whose audio streams need to be analysed in real-time. For a simple experiment, only two cameras placed in the Bar couch will be used. It will be sufficient to have a recent Intel i7 CPU with 8 cores and 16 GB of RAM. For the GPU requirements, an NVIDIA 20 series (such as RTX 2070 or 2080Ti) is needed. To host the AI Module and the Video Storage Module, an SSD with a capacity of 128GB is enough.

When a disruptive situation is detected, the P3 AI Module will send an alarm to the “Alarm Management Tool” in the Cloud Layer indicating which camera has detected the event, so that it can be later presented in the “Train Presentation Tool” (Section 3.1.3). The alarm will be sent using an MQTT broker.

The required hardware, software and connectivity are listed in Table 8.

Table 8 - Data analytics module requirement

usage	GPU	CPU	RAM	SSD	OS	Max power (W)	throughput	user	location
Inference	RTX3090	AMD server Threadripper	64Go	2To	UBUNTU	1000	10 Mbps	UC1/UC4 analytics module	Cloud/Edge



Figure 19 - PC housing (BQT BGW37 - PURE BASE 500DX Black): 232 x 443 x 450 (Width, Height, Depth) in mm

2.3.2.2 P3 Video Storage Module

In the case of detecting an emergency word, there is a need of storing some footage of the event in a P3 Video Storage Module so that it can be reviewed later if necessary. The P3 Video Storage Module will be located in the Edge Layer, in the same hardware than P3 AI Module.

More precisely, the module will store in a buffer the last minutes of the camera stream. When the buffer is full, the older parts of the streams will be replaced by the most recent ones, working as a FIFO queue. This means that, if no alarm is triggered, the recorded video is discarded after some minutes, which allows for a better optimization of the amount of storage needed and a better treatment of passenger's privacy. The size of the buffer (defined by the number of past minutes that are stored) will be set as a customizable parameter.

When a tense situation alarm is triggered by the P3 AI Module, the P3 Video Storage Module will create a permanent copy of the stored buffer as well as the buffer saved after this event. In this way, it can keep a permanent copy of what happen before and after the alarm event is triggered. If necessary, the P3 Cloud Module located in the Cloud Layer can get a copy of the recorded video for a potential investigation of the situational event that triggered the alarm.

The P3 Video Storage Module will get the video and audio stream from the P3 AI Module located in the Edge Layer, which gets the stream directly from the camera using a RTSP connection. This P3 Video Storage Module can be seen as a submodule of the P3 AI Module, meaning that they will be jointly deployed inside the same Docker container in the Edge Layer.

2.3.2.3 P2 AI Module

Obstacles under a train track can be dangerous by causing accidents, or annoying by causing perturbations on the traffic flow. This innovative module plans to construct an AI solution able to help train operator by automatise the detection of such unexpected and potentially dangerous objects. By using LiDAR (Light Detection And Ranging) sensor technology the AI module algorithms will send obstacle detection estimation to the Alarm Management Tool which will analyse the provided information. Finally, an alert may be sent to all trains on the track if necessary.

In regard to classical methods, AI algorithms have proven their superiority for analyse complex recognition tasks. Some new and challenging cutting-edge AI techniques will be tested like Sparse Convolutions [12] with semi- or unsupervised learning. A large choice of dataset for training is available on the Internet which use LiDAR in a Mobile Mapping System (MMS) situation (e.g., KITTI [13]).

The system will prominently use 5G network for data transfer. LiDAR raw data will be captured to an on-board computer and will be sent through 5G connectivity to an edge-level server which will host the AI module. After data processing and formatting, the AI algorithm will analyse the resulting data in order to provide a set of information to the Alarm Management Tool. The set of information will contain indications about the detected obstacle (e.g., dimension, most similar label) and train localization. A schema of the information flow is represented in the Figure 20.

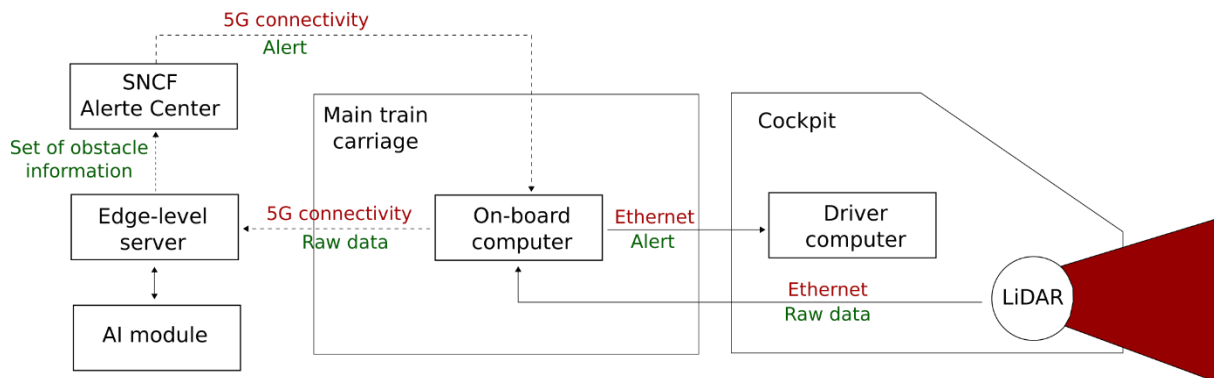


Figure 20 - Schema of the information flow for the obstacle detection system-based AI with LiDAR. The solid arrows indicate the physical connectivity data flow, and the dashed arrows indicate the wireless connectivity data flow. The red texts indicate the connectivity type, and the green texts indicate the transmitted data type.

AI algorithms with LiDAR are quite computationally expensive and there are strong constraints on execution time regarding the data flow. To reach those requirements, one or several powerful GPU are required. For data processing a recent CPU will be sufficient with enough SSD memory and RAM memory.

2.3.2.4 B1 Traffic Generator

A Traffic Generator used for B1 service purposes will be an INTEL NUC device (Next Unit of Computing), that support Ethernet 10 Gbps (and enough resources to generate 2Gbps traffic flows) and Wi-Fi 6.

A similar NUC is installed in the Train Layer and the generated traffic is exchanged between the two PC NUC (see Section 2.3.1.5).

2.3.3 Cloud Layer Compute Requirements

This section describes the compute requirements of the UC3 and UC4 services at the Cloud Layer.

2.3.3.1 UC3 Cloud Servers

The UC3 Cloud Servers are a virtualized private cloud environment. They host every application needed to support any UC3 services. It shall host the P1 IoT Data Processing Tool, the Alarm Management Tool and the P3 Cloud Module. Their functionalities are respectively explained in Section 3.1.1, 3.1.2 and 3.1.3.

The hardware requirement for these servers is quite low, because not a lot of computing is needed. Each application is hosted in a different virtual machine. This simulates a public cloud infrastructure where each application could be hosted in a different location.

2.3.3.2 UC4 components

UC4 components, as EMT cloud server, TP cloud server, EMT client and TP client are the same as the ones used in the automotive UCs. They are also hosted in a virtualized private cloud infrastructure.

3 Software Components

This section describes each of the software components of the use cases functional blocks and how the components are interfaced with the rest of the software components. Two types of interfaces are considered, as described below:

1. Internal interfaces: The internal interfaces are the interfaces between two sub-blocks inside the same functional block. Only one partner is responsible for these internal interfaces. Only a brief description of the internal interface will be provided.
2. External interfaces: The external interfaces are the interfaces between functional blocks. They are the main interfaces to understand the behaviour of the services. If the external interface is between functional blocks which different partners are responsible for, the interface is defined in cooperation with the different partners.

The following figure shows an example of both internal and external interfaces:

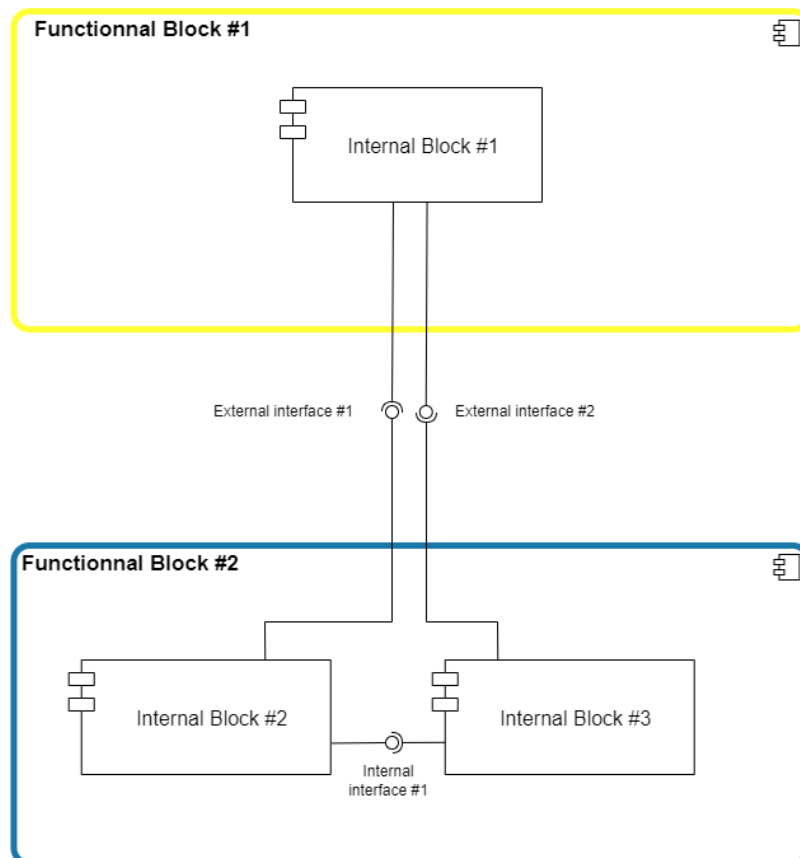


Figure 21 - Example of internal view of functional blocks showing interfaces

Also, the Cross-border MEC Interface that allows services to select and use the most appropriate/closer MEC for better performance is defined for each service in their own subsection in Section 3.1.

To support UC3 services, some software components must be developed specifically for 5GMED. Section 3.1 describes all these software components for each service of UC3 and their interfaces. UC4 is omitted from Section 3.1 because it does not need any specific development to support the railway scenarios. The software necessary to support UC4 in the railway scenario is the same as the one developed for the automotive scenario. To avoid any repetition, this is explained in D4.2 [4]. Finally, Section 3.2 describes the other common software used by all uses cases and services, which are the ACS-GW and the Geolocation Module.

Figure 22 (extracted from D5.1 [2]) shows all the components required to support the UC3 FRMCS Performance Services.

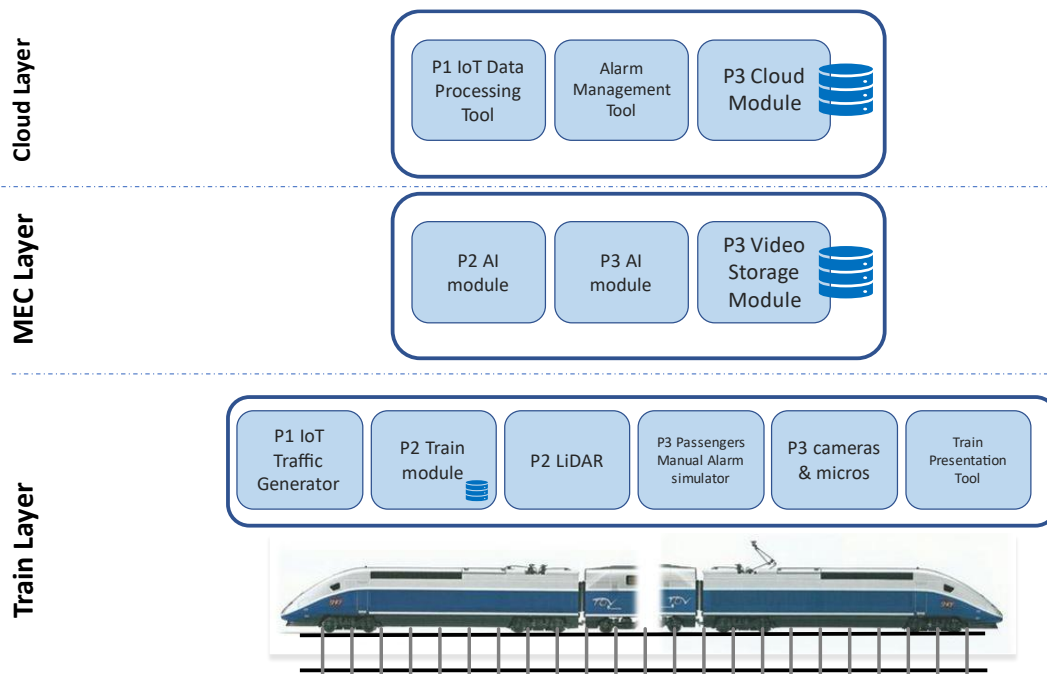


Figure 22 – UC3 FRMCS Performance Services Blocks (extracted from D5.1 [2])

3.1 Service-Specific Software Components

3.1.1 UC3 FRMCS – P1: Advanced Sensor Monitoring on Board

The software components supporting the Use Case 3 – P1 are the P1 IoT Traffic Generator, the P1 IoT Data Processing Tool and the Train Presentation Tool as shown in the figure below. A simplified explanation of the behaviour of UC3 - P1 is provided in D5.1 [2] Section 3.2.1.

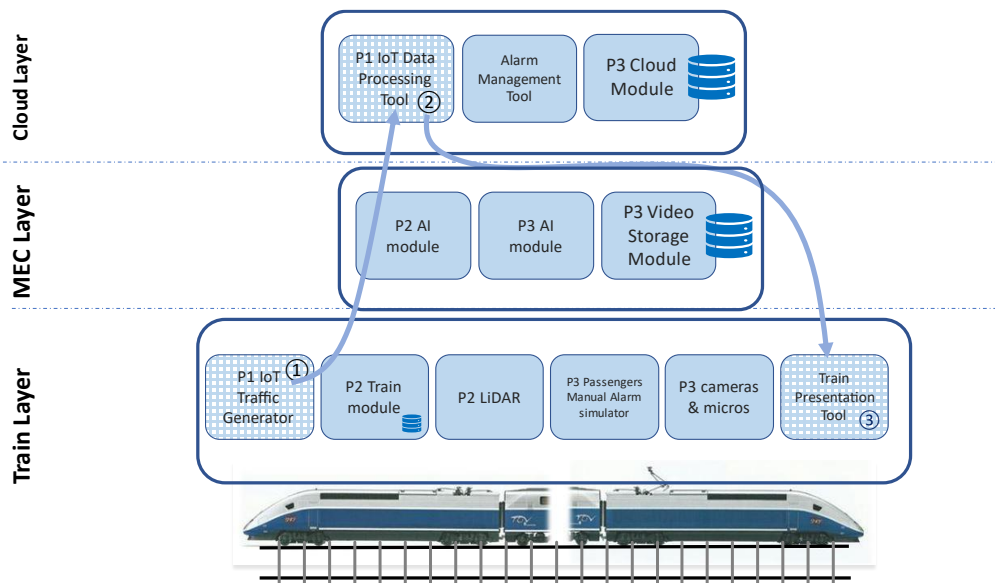


Figure 23 - Behavioural view for FRMCS P1 Advanced Sensor Monitoring on Board (extracted from D5.1 [2])

3.1.1.1 Internal components view

Figure 24 describes the internal interfaces as well as an overview of the external interfaces.

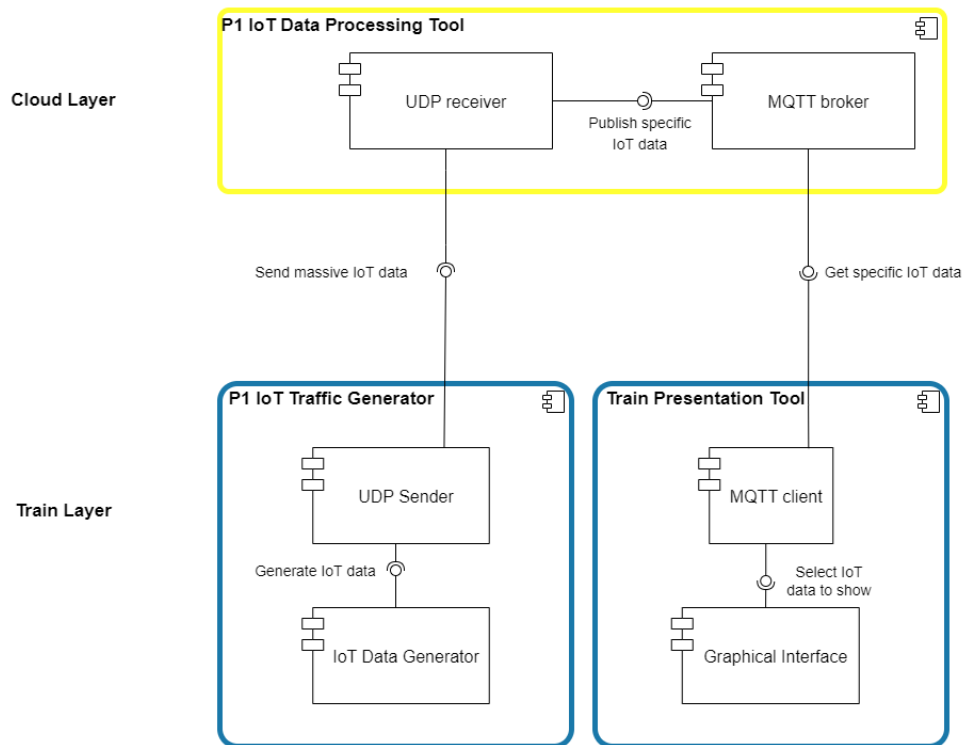


Figure 24 - UC3 - P1 internal view

As it can be observed in Figure 24, there is no direct internal interface between the P1 IoT Traffic Generator and the Train Presentation Tool. In fact, both applications interact with each other, but through the P1 IoT Data Processing Tool.

3.1.1.2 Components On-board the Train

3.1.1.2.1 P1 IoT Traffic Generator

The embedded simulator, which is used in UC3 – P1 [2], is an IoT Traffic Generator. It will send to the P1 IoT Data Processing Tool (see Section 3.1.1.4) in the Cloud Layer a generated file containing 4000 simulated variables every 100ms (JSON encoded). The Train Presentation Tool (see below) will be used to monitor the variation of data from two specific sensors as described in next subsection.

It is composed of two internal functional blocks (see Figure 24):

1. The **IoT Data Generator** produce the 4000 IoT variables and store them in a JSON file. The variables are updated every 100 milliseconds.
2. The **UDP Sender** put the JSON file in the payload of a UDP datagram, then send it to the P1 IoT Data Processing Tool.

The program runs on a Linux Operating System (it is developed in C/python). It creates the train variables and sends them to a server (to a specific IP@ and port) using UDP. For UC3 P1, the server is the P1 IoT Data Processing Tool. The ACS-GW is used as a gateway for sending frames to the server in

the cloud. Most variables are static, set to an arbitrary value, except two variables following respectively a sine and a square wave. These two specific variables are following predictable patterns in order to easily visualize them on the Train Presentation Tool (see below), and to visually track any packet loss or packet reordering.

3.1.1.2.2 Train Presentation Tool

The Train Presentation Tool is used to present the processed IoT data in a very simplified way. This tool is located in the train to simplify the showcase of the service and avoid the need to have a person located in the Cloud Layer site checking the results. This is implemented by connecting to the MQTT broker of the P1 IoT Data Processing Tool in the Cloud Layer.

It is composed of two internal functional blocks (see Figure 24):

1. The **MQTT Client** subscribe to two topics¹² on the MQTT broker of P1 IoT Data Processing Tool, and regularly receive the updated value of two variables sent by P1 IoT Traffic Generator. The updated values are then sent to the Graphical Interface.
2. The **Graphical Interface** displays the variables received by the MQTT Client.

The variables showcased in the Train Presentation Tool are the ones varying following a sine and a square wave form. The variables will be displayed as soon as they are received. This will allow us to graphically see any transmission disturbance.

The Train Presentation Tool is also used independently by UC3 – P2 and UC3 – P3. The internal functional blocks for P2 and P3 are not included in Figure 24, as well as their interfaces. More information is included in subsections 3.1.2 for P2 and Section 3.1.3 for P3.

3.1.1.3 Components at the MEC Layer

There is not any functional block in MEC Layer for UC3 – P1.

3.1.1.4 Components at the Cloud Layer

3.1.1.4.1 P1 IoT Data Processing Tool

The P1 IoT Data Processing Tool will be developed for its integration in the Cloud Layer. It will receive the data coming from the P1 IoT Traffic Generator. The reception of the data will feed an MQTT¹³ broker to which the Train Presentation Tool will connect, subscribing to some variables, so that they can be graphically displayed on any client laptop/PC.

It is composed of two internal functional blocks (see Figure 24):

¹² In the MQTT protocol, the data is organised in multi-level topics. For example, a variable can be named “/maintopic/trainvariable/variable1”. More information on MQTT specification: https://docs.oasis-open.org/mqtt/mqtt/v5.0/os/mqtt-v5.0-os.html#_Toc3901107

¹³ MQTT means “Message Queuing Telemetry Transport”. It is a commonly used protocol for sending and receiving IoT data. MQTT specifications can be found on their website [15]

1. The **UDP receiver** get the UDP datagram from P1 IoT Traffic Generator, parse the JSON file included in the UDP datagram and extract each variable. Then the UDP receiver publish the variables to the MQTT broker. Each variable is stored in a different topic¹⁴.
2. The **MQTT broker** receives the variables from the UDP receiver with their corresponding topic. Then, any MQTT client can subscribe to one or more topics to receive the corresponding variables.

For this to work, the TCP port where the MQTT broker is listening (TCP/1883) shall be open in reception on the platform running the software (in the cloud) and outgoing connections allowed (or at least stateful connection allowed). The software has been developed on a Linux Operating System (ubuntu) and is hosted in a virtual machine in the UC3 Cloud Servers (see Section 2.3.3.1) in the Cloud Layer.

3.1.1.5 External interfaces

The internal view of UC3 P1 Components are provided in Section 3.1.1.1.

The specifications of the external interfaces are described in the following tables:

Interface name	Get specific IoT data				
Protocol	MQTT	Provider	P1 IoT Data Processing Tool	Consumer	Train Presentation tool
Input data	iot_data_id				
Output data	iot_data_value				
Description	<p>The Train Presentation Tool in UC3 P1 will subscribe to two topics/variables of the MQTT broker of P1 IoT Data Processing Tool.</p> <p>The subscribed subject will indicate which IoT data is queried.</p> <p>The IoT Data Processing Tool will send a new iot_data_value as soon as the data is refreshed.</p>				

Interface name	Send massive IoT data				
Protocol	UDP	Provider	P1 IoT Traffic Generator	Consumer	P1 IoT Data Processing Tool

¹⁴ In the MQTT protocol, the data is organised in multi-level topics. For example, a variable can be named “/maintopic/trainvariable/variable1”. More information on MQTT specification: https://docs.oasis-open.org/mqtt/mqtt/v5.0/os/mqtt-v5.0-os.html#_Toc3901107

Input data	N/A
Output data	4000 variables
Description	<p>Send the IoT data in a JSON file to the P1 IoT Data Processing Tool.</p> <p>The JSON file format is a simple tree listing all IoT variables.</p> <p>It should look like this:</p> <pre> { "Version": "v1.1", "Date": "2022-08-24 13:53:34.4069 +0000", "frame_nb": 396, "TrainID": "z99999", "changing_variables": { "sin": 4, "square": 0 }, "variables": { "Var_0000": 0, "Var_0001": 1, "Var_0002": 2, "Var_0003": 3, "Var_0004": 4, "Var_0005": 5, "Var_0006": 6, "Var_0007": 7, "Var_0008": 8, "Var_0009": 9, "Var_0010": 10, "Var_0011": 11, "Var_0012": 12, "Var_0013": 13, "Var_0014": 14, "Var_0015": 15 [...] } } </pre>

3.1.1.6 Cross-border MEC Interface

As P1 service doesn't have any functional block in the MEC Layer, no Cross-border MEC Interface is defined for P2 service.

3.1.2 UC3 FRMCS – P2: Obstacle Detection

The software components supporting the Use Case 3 – P2 are the P2 LiDAR, the P2 Train Module, the P2 AI Module, the Alarm Management Tool and the Train Presentation Tool. A simplified explanation of the behaviour of UC3 – P2 is provided in D5.1 [2] Section 3.2.2.

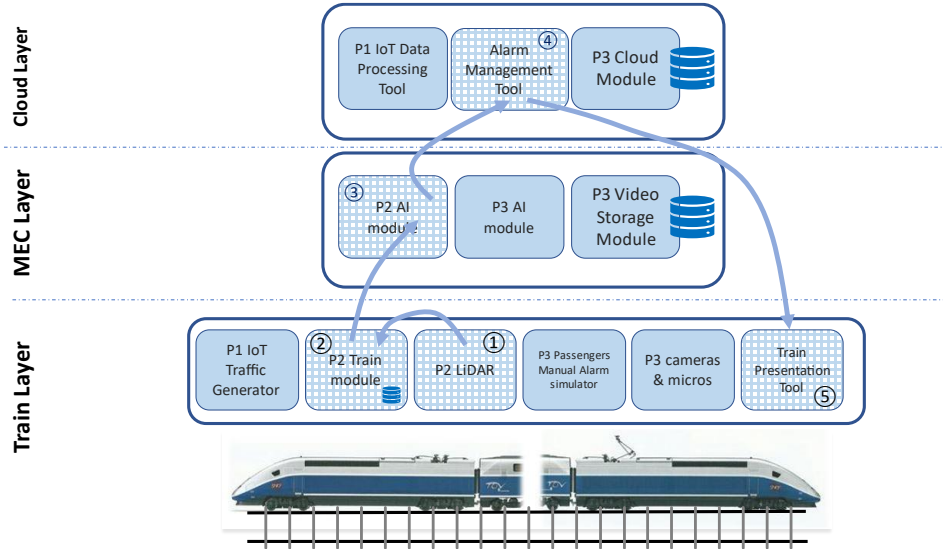


Figure 25 - Behavioural view for FRMCS P2 Obstacle Detection from D5.1 [2]

3.1.2.1 Internal components view

In the Figure 26 are described the internal interfaces as well as an overview of the external interfaces. The Cross-border MEC Interface of the UC3 P2 service is described in Section 3.1.2.6.

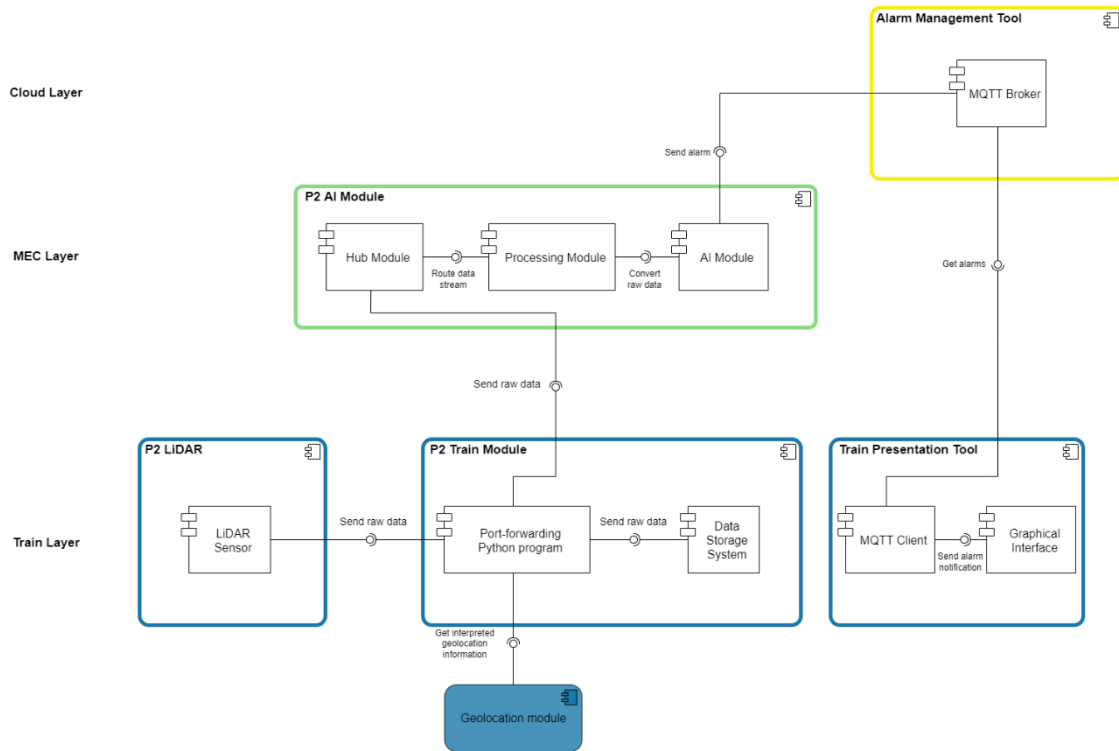


Figure 26 - UC3 P2 internal view

3.1.2.2 Components On-board the Train

3.1.2.2.1 P2 LiDAR

UC3 – P2 aims at providing support for obstacle identification on the track parallel to the one followed by the train. LiDAR sensors will scan the train surrounding environment and provide raw data which, after processing, will give a set of distance measurements called point cloud. These point clouds will be aggregated to obtain a dynamic 3D map along the train trajectory and forwarded to the MEC Layer in the ground.

It is composed of one internal functional block (see Figure 26):

1. **LiDAR Sensor:** The LiDAR Sensor scans the train surroundings, generating a dynamic 3D map composed of point cloud. The 3D map is encapsulated in a UDP datagram then send to the Port-forwarding P2 Train Module.

All the communication flows will be unidirectional and will use the User Datagram Protocol (UDP) to communicate, the latency being privileged to the loss of a packet which can be coped with by the AI module.

3.1.2.2.2 P2 Train Module

The LiDAR cannot directly send its captured data to the P2 AI Module in the MEC Layer. The P2 Train Module can receive the data from the LiDAR then forward them to its appropriate destinations.

It is composed of two internal functional blocks (see Figure 26):

1. The **Port-forwarding Python program** listen for the flow of data point sent by the LiDAR and forward it to the P2 AI Module in the MEC Layer. Also, a copy of the data stream is sent to the Data Storage System.
2. The **Data Storage System** save the data sent by the LiDAR for archiving and later comparison. With the stored dataset it will be possible to process the data later without using the Train to Ground connectivity. This will allow us to determine the impacts of the connectivity between the Train and the MEC (packet loss...).

In the cross-border situation the data flow needs to be redirected to another appropriate MEC server. By using the information of the Geolocation Module, the Port-forwarding Python program will switch the IP address of the P2 AI Module. The communication with the first P2 AI Module will be maintained during a short period of time as the connection with the next MEC server is established to process a smooth handover.

3.1.2.2.3 Train Presentation Tool

The Train Presentation Tool is used to present the alarms sent by the P2 AI Module. It simulates a control centre of a train operator, that will take decision based on the received alarms. This tool is located in the train to simplify the showcase of the service and avoid the need to have a person located in the Cloud Layer site checking the results. This is implemented by connecting to the MQTT broker of the Alarm Management Tool in the Cloud Layer.

It is composed of two internal functional blocks (see Figure 26):

1. The **MQTT Client** subscribe to a topic¹⁵ on the MQTT broker of Alarm Management Tool. When the P2 AI Module will send an alarm to the Alarm Management Tool, the MQTT broker will forward it to the MQTT Client. The alarm is composed of a JSON file with details about the alarm (position of the obstacle, size, type...). Then, the JSON file is sent to the Graphical Interface to be displayed.
2. The **Graphical Interface** displays the alarm details received by the MQTT Client.

The Train Presentation Tool is also used independently by UC3 – P1 and UC3 – P3. The internal functional blocks for P1 and P3 are not included in Figure 24, as well as their interfaces. More information is included in subsections 3.1.1 for P1 and 3.1.3 for P3.

3.1.2.3 Components at the MEC Layer

3.1.2.3.1 P2 AI Module

An AI algorithm in the P2 AI Module implemented in the MEC Layer will provide obstacle detection estimations, based on the information sent by the P2 Train Module on-board the train. A summary of the detected obstacle, with a description of the obstacle nature and dimension, is then sent to the Alarm Management Tool in the Cloud Layer.

It is composed of three internal functional blocks (see Figure 26):

1. The **Hub Module** forward the data sent by the P2 Train Module to the Processing Module. In case of a cross-border event it is also able to send the data to the other MEC server.
2. The **Processing Module** converted the UDP datagrams into a point cloud and then send them to the AI Module.
3. The **AI Module** will run an AI model to detect an obstacle in the data sent by the Processing Module. When an obstacle is detected, a formatted JSON file is sent via MQTT protocol to the Alarm Management Tool in the Cloud Layer. The latter will dispatch an alarm to the trains running on the obstructed track. In the trial, the alarm will be displayed in the Train Presentation Tool that will receive this file in the train.

3.1.2.4 Components at the Cloud Layer

3.1.2.4.1 Alarm Management Tool

The Alarm Management Tool is a very simple software simulating a train control centre. It receives the alarms from trains and takes actions: alert a specific train about a malfunction, stop all trains because of the presence of an obstacle... In the trial, the Alarm Management Tool only receives the alarms and forward them to the Train Presentation Module for visualization.

¹⁵ In the MQTT protocol, the data is organised in multi-level topics. For example, a variable can be named “/maintopic/trainvariable/variable1”. More information on MQTT specification: https://docs.oasis-open.org/mqtt/mqtt/v5.0/os/mqtt-v5.0-os.html#_Toc3901107

It is composed of one internal functional block (see Figure 26):

1. The **MQTT Broker** forward the alarm received from the P2 AI Module to the Train Presentation Tool.

The Alarm Management Tool is inside an Ubuntu VM hosted in UC3 Cloud Servers (see Section 2.3.3.1) in the Cloud Layer.

The Alarm Management Tool is shared with UC3 – P3.

3.1.2.5 External interfaces

The internal view of UC3 – P2 Components are provided in Section 3.1.2.1. The specifications of the external interfaces are described in the following tables:

Interface name	Send raw data				
Protocol	UDP	Provider	P2 LiDAR	Consumer	P2 Train Module
Input data	N/A				
Output data	UDP packets				
Description	Raw data stream containing the information captured by the LiDAR.				

Interface name	Send raw data				
Protocol	UDP	Provider	P2 Train Module	Consumer	P2 AI Module
Input data	N/A				
Output data	UDP packets				
Description	Raw data stream containing the information captured by the LiDAR.				

Interface name	Send alarm				
Protocol	MQTT	Provider	P2 AI Module	Consumer	Alarm Management Tool
Input data	Alarm event (JSON)				
Output data	N/A				
Description	The Alarm Management Tool of the UC3 Cloud Server will be listen to any published alarm from the P2 AI Module. Whenever an obstacle is detected, the P2 AI Module will publish a message to the MQTT alarm topic containing a JSON file with several information about the obstacle (position, size...).				

Interface name	Get alarms				
Protocol	MQTT	Provider	Alarm Management Tool	Consumer	Train Presentation Tool
Input data	Alarm event (JSON)				
Output data	N/A				
Description	The Train Presentation Tool will subscribe to a MQTT alarm topic in order to receive alarms from the P2 AI Module. The alarm includes a JSON file with several information about the obstacle (position, size...).				

Interface name	Get interpreted geolocation information				
Protocol	UDP Multicast	Provider	On-board Geolocation Module	Consumer	P2 Train Module
Input data	None				
Output data	Geographical latitude and longitude Zone (These values must be in correspondence with the zone values) Country Train Speed				
Description	The positioning system will send periodically (period 0.5 sec) to a multicast group the output data. The P2 Train Module will use the "Country" information to determine which MEs it shall use.				

3.1.2.6 Cross-border MEC Interface

In the final architecture, two P2 AI Modules will be implemented, in two MEC Servers along the tracks. The closest P2 AI Module to the train should always be used, for better performance. So, when the train is running, the handover between two P2 AI Modules has been implemented, and the interfaces needed are described by the Figure 27:



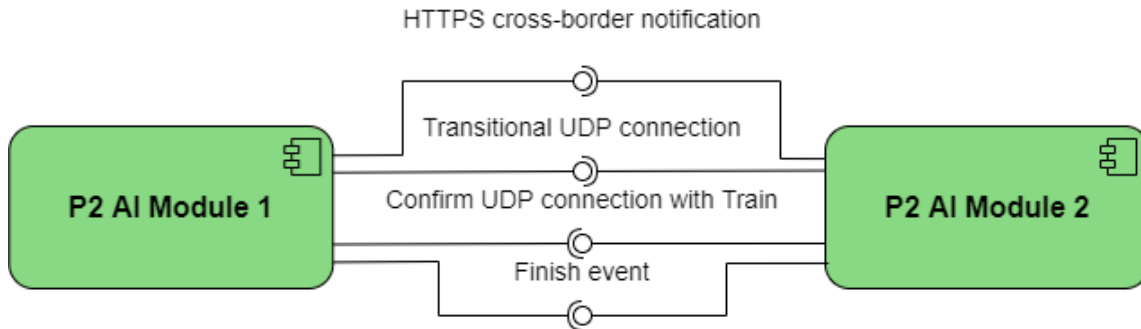


Figure 27 - Interfaces between two P2 AI modules

In the cross-border situation the data flow needs to be redirected to another appropriate P2 AI Module. By using the information of the Geolocation Module, the Port-forwarding Python program will switch the IP address of the P2 AI Module. The communication with the first P2 AI Module will be maintained during a short period of time as the connection with the next MEC server is established to process a smooth handover.

Interface name	Notify cross-border				
Protocol	HTTPS	Provider	P2 AI Module 1	Consumer	P2 AI Module 2
Input data	notifyCrossborder				
Output data	N/A				
Description	The active P2 AI Module (Module 1) will notify the inactive P2 AI Module (Module 2) that the train is about to cross the border, so that the latter can open a new UDP connection with the on-train LiDARs.				

Interface name	Get transitional data stream				
Protocol	UDP	Provider	P2 AI Module 1	Consumer	P2 AI Module 2
Input data	getTemporaryStream				
Output data	UDP				
Description	During the transition of the UDP connection with the on-train LiDARs, the Module 1 established an UDP connection with the Module 2 in order to provide for the latter the transitional data stream.				

Interface name	Confirm UDP connection				
Protocol	HTTPS	Provider	P2 AI Module 2	Consumer	P2 AI Module 1
Input data	confirmUDPConnection				
Output data	N/A				
Description	Once the P2 AI Module 2 has established an UDP connection with the on-train LiDARs, it will inform the old P2 AI Module (Module 1) about this successful connection.				

Interface name	Finish event				
Protocol	HTTPS	Provider	P2 AI Module 2	Consumer	P2 AI Module 1
Input data	finishEvent				
Output data	N/A				
Description	Once every step of the transition is finished, P2 AI Module 2 will send a finish event to the old Module (Module 1) to confirm that the whole handover process was successful. Module 1 will close the UDP connections and will become the inactive P2 AI Module.				

3.1.3 UC3 FRMCS – P3: Passenger Safety and Comfort

The software components supporting the Use Case 3 – P3 are the P3 cameras & micros, the P3 AI Module, the P3 Video Storage Module, Alarm Management Tool, the Train Presentation Tool, the P3 Passengers Manual Alarm Simulator and the P3 Cloud Module. A simplified explanation of this behaviour of UC3 – P3 is provided in D5.1 [2] Section 3.2.3. Other behaviours are also described for UC3 – P3.

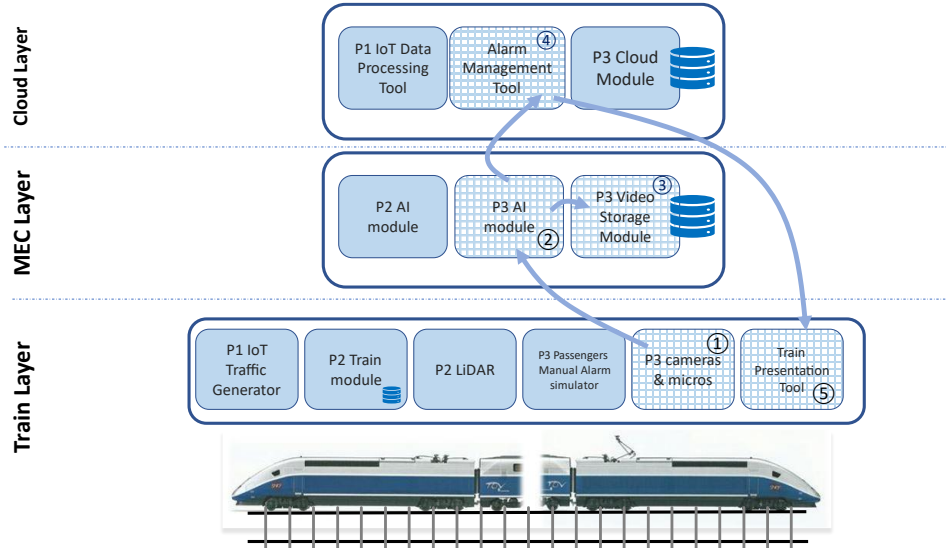


Figure 28 – One of the behavioural view for FRMCS P3 Passenger safety and comfort from D5.1 [2]

3.1.3.1 Internal components view

In the Figure 29 are described the internal interfaces as well as an overview of the external interfaces. The Cross-border MEC Interface is described in Section 3.1.3.6.

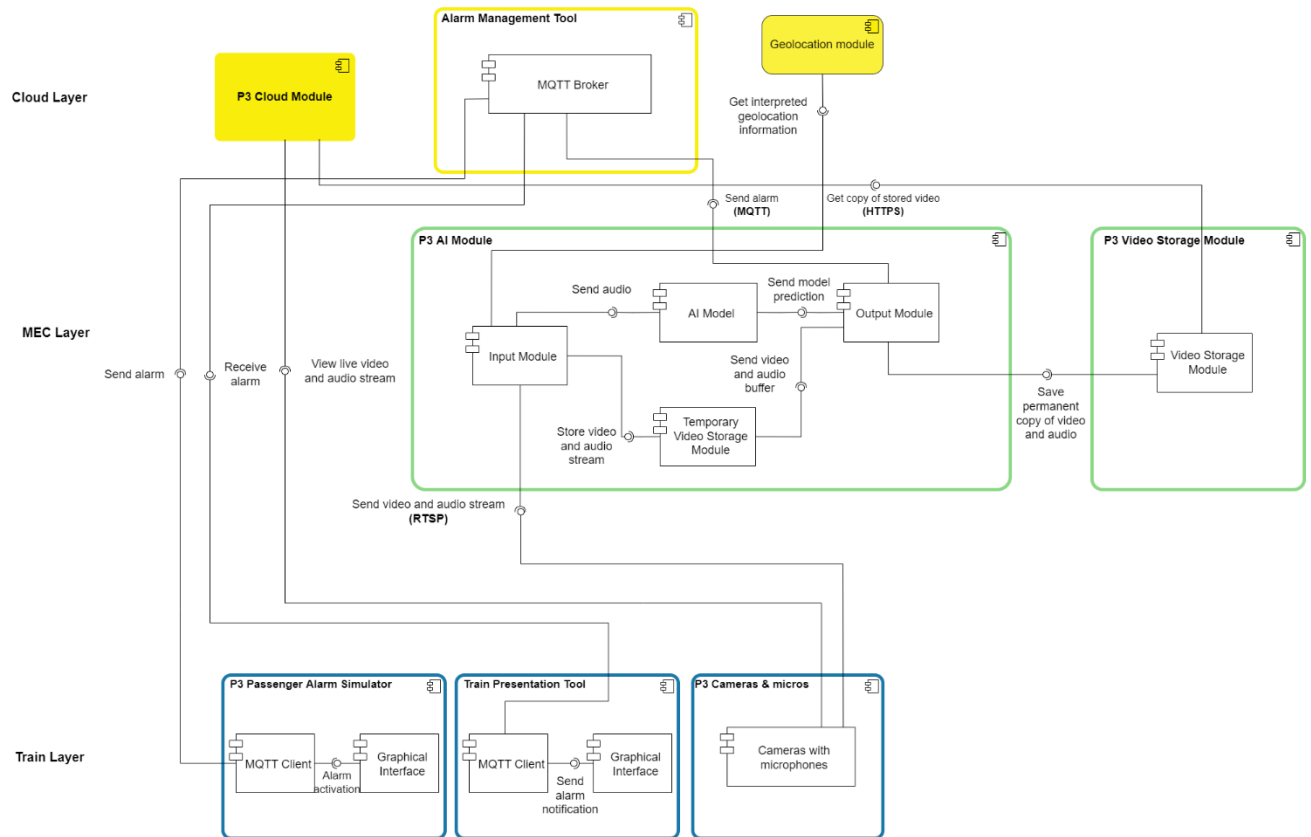


Figure 29 - UC3 P3 internal view

3.1.3.2 Components On-board the Train

3.1.3.2.1 P3 Cameras & micros

The cameras used for UC3 – P3 are described in Section 2.3.1.3. As it is an off-the-shelf component, no software development was necessary. The main functionality that will be used in 5GMED is the integrated RTSP server, that will allow to get the video and audio feed from the cameras.

3.1.3.2.2 P3 Passenger Alarm Simulator

The P3 Passenger Alarm Simulator enable an operator in the train to trigger an alarm which is sent to the Alarm Management Tool. This alarm follows the same behaviour than an alarm sent by the P3 AI Module and has the same consequences (see Section 3.1.3.3 below).

It is composed of two internal functional blocks (see Figure 29):

1. The **Graphical Interface** display to the user some buttons to trigger alarms. When a button is pressed, a notification is sent to the MQTT Client.

2. The **MQTT Client** will receive the notification from the Graphical Interface, then it will publish a MQTT message to the MQTT broker in the Alarm Management Tool. This MQTT includes some information about the alarm (position of the alarm in the train...).

3.1.3.2.3 Train Presentation Tool

The Train Presentation Tool is used to present the alarms sent by the P3 AI Module and the P3 Passenger Alarm Simulator. It simulates a control centre of a train operator, that will take decision based on the received alarms. This tool is located in the train to simplify the showcase of the service and avoid the need to have a person located in the Cloud Layer site checking the results. This is implemented by connecting to the MQTT broker of the Alarm Management Tool in the Cloud Layer.

3.1.3.3 Components at the MEC Layer

3.1.3.3.1 P3 AI Module

The P3 AI Module is the main software component for UC3 – P3. It will analyze the audio feed from the cameras on-board to detect any dangerous situation. When a dangerous situation is identified, an alarm is sent to the Alarm Management Tool, which simulate the train control center, to take appropriate actions. In the trial the alarm will be displayed on the Train Presentation Tool.

It is composed of several internal blocks:

1. The **Input Module** receives the live video and audio stream from the CCTV cameras inside the train. A temporary copy of this stream is saved in a **Temporary Video Storage Module**.
2. The **AI model** will analyze the audio stream received by the Input module to create a transcription of the speech contained in it. The audio transcript will be sent to an **Output Module**.
3. The **Output Module** is responsible for taking several actions:
 - a. It will first detect if any emergency word is present on the speech transcript, which means that a potentially disruptive situation is taking place inside the train. Here, the Output Module may implement several measures to minimize the trigger of a false alarm. For example, it may wait a few seconds to check if the emergency word is repeated in more than one consecutive block of the input audio.
 - b. If an emergency word is detected, it will send an MQTT alarm to the Alarm Management Tool in the Cloud Layer, indicating the timestep of the event and the camera location inside the train.
 - c. Finally, it will retrieve the stream in the Temporary Storage Module and will save a permanent copy inside the **Video Storage Module**. This will allow the P3 Cloud Module in the Cloud Layer to access this copy of the video to check the video and audio of the event that triggered the alarm.

The deployment of this P3 AI Module will be performed using a Docker container with Ubuntu 20.04 LTS and all the Python packages installed. It will open a Real Time Streaming Protocol (RTSP) connection to the cameras to get, process and store the live video and audio streams.

3.1.3.3.2 P3 Video Storage Module

The P3 Video Storage Module did not need any development. It is only composed of an FTP server to receive the video files from the P3 AI Module, and a HTTP server to allow a remote module (P3 Cloud Module for example) to download stored video files.

3.1.3.4 Components at the Cloud Layer

3.1.3.4.1 Alarm Management Tool

3.1.3.4.2 P3 Cloud Module

The P3 Cloud Module did not need any development. It is only composed of a web browser to access

3.1.3.5 External Interfaces

Interface name	View live video and audio stream				
Protocol	HTTPS	Provider	P3 cameras & micros	Consumer	P3 Cloud Module
Input data	Camera IP address, port, user and password				
Output data	Camera live stream				
Description	The P3 Cloud Module in the Cloud Layer can request to view the live stream of any camera in the train using the camera's web browser application. To do so, it will have to specify the camera IP address, port, user and password.				

Interface name	Receive alarm				
Protocol	MQTT	Provider	Alarm Management Tool	Consumer	Train Presentation Tool
Input data	Alarm event				
Output data	N/A				
Description	The Train Presentation Tool will subscribe to a MQTT topic, listening for alarm. The Alarm Management Tool will send the alarm from the Cloud Layer.				

Interface name	Send video and audio stream				
Protocol	RTSP	Provider	P3 cameras & micros	Consumer	P3 AI Module
Input data	Camera IP address, port, user and password				
Output data	Camera live stream				
Description	The P3 AI Module will open an RTSP connection with the CCTV cameras of UC3 P3. The CCTV cameras will send the video and audio stream to the P3 AI Module, so it can be analyzed to detect disruptive situations.				

Interface name	Send manual alarm				
Protocol	MQTT	Provider	P3 Passenger Alarm Simulator	Consumer	P3 AI Module
Input data	Alarm event				
Output data	N/A				
Description	A passenger inside the train can trigger a manual alarm in case of disruptive situation. The P3 AI Module will receive such alarm using a MQTT broker.				

Interface name	Send alarm				
Protocol	MQTT	Provider	P3 AI Module	Consumer	Alarm Management Tool
Input data	Alarm event				
Output data	N/A				
Description	The Alarm Management Tool of the Cloud Layer will be subscribed to a MQTT topic in order to receive alarms from the P3 AI Module. Whenever a disruptive situation is detected, the P3 AI Module will publish a message to the MQTT topic containing the timestamp, the camera ID and the camera location within the train.				

Interface name	Get copy of stored video				
Protocol	HTTPS	Provider	P3 Video Storage Module	Consumer	P3 Cloud Module



Input data	getVideo
Output data	Video file
Description	If a disruptive situation was detected, a video file containing the recording of such event will be available in the P3 Video Storage Module. The P3 Cloud Module in the Cloud Layer can get this video file to review it.

Interface name	Save permanent copy of video and audio				
Protocol	FTP	Provider	P3 Cloud Module	Consumer	P3 Video Storage Module
Input data	Video file				
Output data	N/A				
Description	If a disruptive situation was detected, a video file containing the recording of such event will be stored in the P3 Video Storage Module. It is send to the P3 Video Storage Module through FTP.				

Interface name	Get interpreted geolocation information				
Protocol	UDP	Provider	On-ground Geolocation Module	Consumer	P3 AI Module
Input data	GetAllData				
Output data	Geographical latitude and longitude Zone (These values must be in correspondence with the zone values) Country Train Speed				
Description	The On-ground Geolocation Module update the output data to the project component that requires it. The info will be updated with a maximum difference of 0.5 sec. The P3 AI Module will use the "Country" information to determine which MEs it shall use.				

3.1.3.6 Cross-border MEC Interface

In the cross-border situation the data flow needs to be redirected to another appropriate P3 AI Module. By using the information of the Geolocation Module, the active P3 AI Module will detect when a cross-border event occurs and will warn the inactive P3 AI Module. The inactive P3 AI Module will activate and will connect to the on-board camera with RTSP. The communication with the first P3 AI Module will be maintained during a short period of time as the connection between the new P3 AI Module is established to process a smooth handover. Then, the new P3 AI Module will get a temporary video file recorded by the old P3 AI Module while the new one was connecting to the camera. Finally, when the transfer is done the old P3 AI Module will enter in an inactive state.

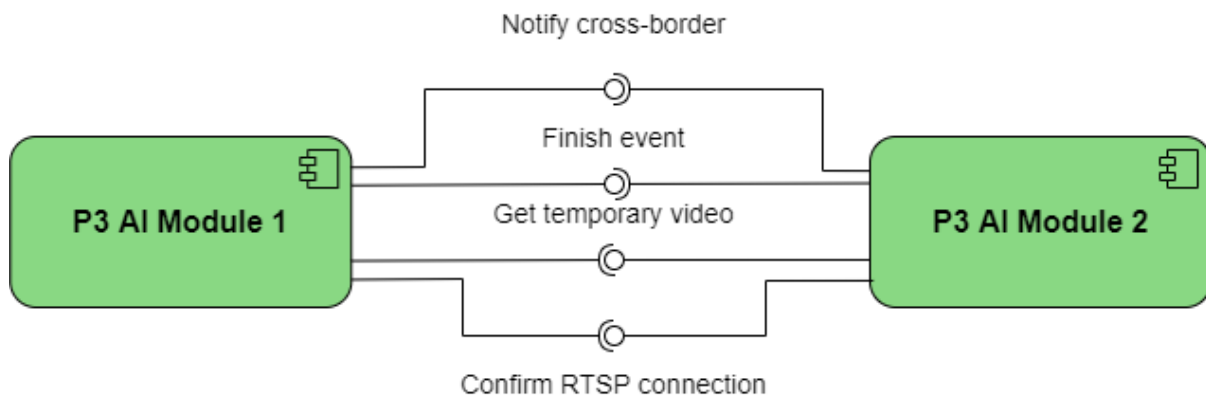


Figure 30 - Interfaces between two P3 AI Modules

Interface name	Notify cross-border				
Protocol	HTTPS	Provider	P3 AI Module 1	Consumer	P3 AI Module 2
Input data	notifyCrossborder				
Output data	N/A				
Description	The active P3 AI Module (Module 1) will notify the inactive P3 AI Module (Module 2) that the train is about to cross the border, so that the latter can open a new RTSP connection with the on-train cameras.				

Interface name	Confirm RTSP connection				
Protocol	HTTPS	Provider	P3 AI Module 2	Consumer	P3 AI Module 1
Input data	confirmRTSPConnection				
Output data	N/A				
Description	Once the P3 AI Module 2 has established an RTSP connection with the on-train cameras, it will inform the old P3 AI Module (Module 1) about this successful connection.				

Interface name	Get temporary video				
Protocol	HTTPS	Provider	P3 AI Module 1	Consumer	P3 AI Module 2
Input data	getTemporaryVideo				
Output data	Video				
Description	Once the new RTSP connection has been established, the new active P3 AI Module (Module 2) will get the temporary video stream that was stored in the old P3 AI Module (Module 1).				

Interface name	Finish event				
Protocol	HTTPS	Provider	P3 AI Module 2	Consumer	P3 AI Module 1
Input data	finishEvent				
Output data	N/A				
Description	Once the new active P3 AI Module (Module 2) has successfully received the temporary video, it will send a finish event to the old Module (Module 1) to confirm that the whole handover process was successful. Module 1 will close the RTSP connection and will become the inactive P3 AI Module.				

3.1.4 UC3 – Business 1: High-Quality Wi-Fi to Passengers

No software development is involved for UC3 – Business 1 modules, as off-the-shelf components will be used.

3.1.5 UC3 – Business 2: Multi-tenant Mobile Service for Passengers

No software development is involved for UC3 – Business 2 modules, as off-the-shelf components will be used.

3.2 Common Software Components

This section describes the software components required by all services of the use cases in the railway scenario: the ACS-GW on-board the train and Geolocation Module.

3.2.1 ACS-GW On-Board the Train

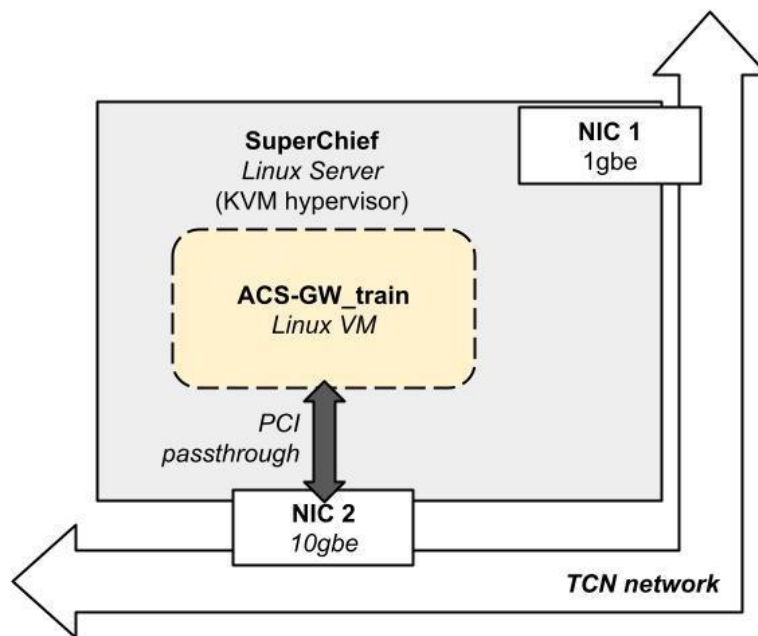


Figure 31 - SuperChief module diagram

To develop the ACS-GW module described in section 2.2.4, as we can see from the Figure 31, a Virtual Machine will be implemented on the server, **ACS-GW_train**. **ACS-GW_train** will implement the **Adaptative Communication System**. The VM have a group of isolated and dedicated CPUs as well as NIC, so that performance is not deteriorated.

3.2.1.1 Internal components view

3.2.1.1.1 ACS-GW Virtual Machine

On **ACS-GW_train** Virtual Machine there will be a **Linux based operating system** connected to **NIC2** through a passthrough connection. This VM will virtualize the functional architecture of the **ACS-GW** composite with the following layers:

- Aggregation
- Classification
- Flow Tracking and QoS monitoring
- Forwarding orchestrator

- IP mobility
- Flow Dispatcher

Where the **Aggregation layer** aggregates the data traffic coming from different end user devices and radio access units. The **Classification layer** associates a set of target QoS KPIs to the incoming application flows. The **Flow Tracking and QoS monitor layer** keep track of all the active application flows and monitor a set of operational QoS parameters. The **Forwarding orchestrator layer** monitors the compliance of the target QoS KPIs with the current measured KPIs and enforces the packet forwarding through the particular logical network slice assigned to the active application flows. The **Flow Dispatcher** forwards the input flows over the proper Radio Access (RA) units. Some of these layers will be deployed directly in the kernel through the use of **eBPF (extend-Berkeley Packet Filter)** (see below) and some in User Space.

More information about ACS-GW behaviour is presented in D5.1 [2] Section 4.2.2.

ACS_GW_train will be seen by the network as a default gateway so that all outgoing and incoming packets are transparently intercepted and processed by all layers of the above-mentioned functional pipeline.

3.2.1.1.2 eBPF (extend-Berkeley Packet Filter)

Some layers listed in the section above will be implemented through eBPF. The optimal point in a system to implement monitoring/observability, networking, and security functions has always been the Linux Kernel but as we can understand this requires changing kernel source code or loading kernel modules with a high risk of incur in kernel panic error. To remedy this, eBPF was developed, which allows developers to run sandboxed programs in the Linux kernel without modifying the kernel source code or loading kernel modules. The programmability of the Linux kernel means that the software infrastructure can use the existing layer, making them more intelligent and with new features without adding complexity, Figure 32.

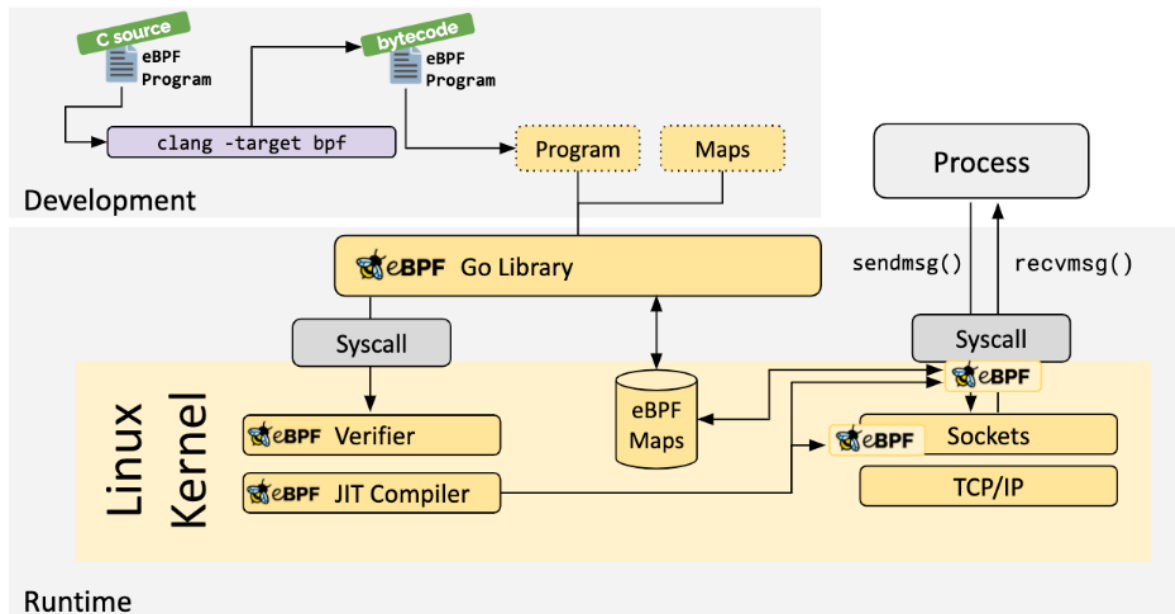


Figure 32 – ACS-GW and e-BPF¹⁶

3.2.1.1.3 Graphical Interface

The *SuperChief* server will export a GUI that has two fundamental goals:

Show the QoS parameters of each radio access network, including Data Rate, latency, and packet loss

Show the current position of the train on a map

Provide a simple control interface to interact with the **ACS-GW** (start/stop, load configuration, enable debug mode, command shell)

This tool will be implemented as a dynamic web-based application and the data feed will come directly from the **ACS-GW_train** VM that will implement a real time data interface to export the measurement and the train position.

This GUI has a clear administrative purpose, but it is worth noting that implementing it as a web application allows to use it also in other contexts. For example, it could be easily displayed to the passengers on the informational monitors.

3.2.2 Geolocation module

The 70 GHz radio equipment installed on both train heads has a GNSS module, but it is not designed to handle geolocation requests from a lot of clients. Instead of allowing all the project components to query the 70GHz radio, the geolocation module is responsible to provide the train location to any project component that will need it.

The information provided by this module is:

¹⁶ <https://ebpf.io/>

- Train absolute position: Latitude and longitude
- Zone (A:5G Open RAN France + satellite, B: Tunnel, C:5G+70GHz+satellite Spain, D:5G+satellite Spain; E:5G Spain with satellite backhaul). This zone map must match with the zones used by the ACS-GW units to forward the data according to the coverage of the different RATs across the corridor.
- Country (France or Spain): A+B=France; C to F: Spain
- Train Speed

This information will be updated each 0.5 sec.

3.2.2.1 Internal components view

There are two different versions of this software module: one for the train and other for the ground. The main difference between the train unit and the ground units is the way in that this information is updated and provided.

The entire geolocation system is described in Figure 33.

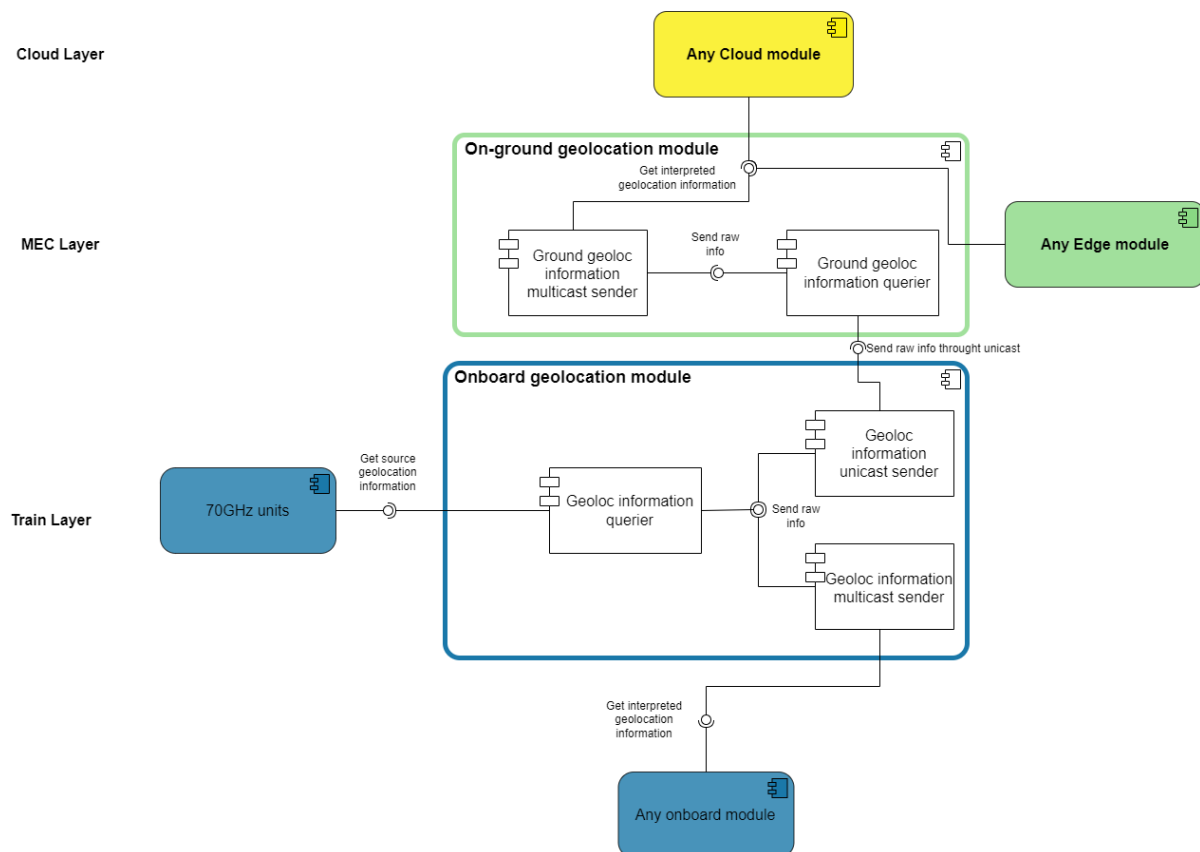


Figure 33 - Geolocation module internal view

3.2.2.1 Components On-board the Train

3.2.2.1.1 On-board Geolocation Module

The On-board Geolocation Module will request both 802.11ad 70 GHz units each 0.5 sec. Once the response is received from both antennas, according to train direction, the front unit is chosen as train position. With the acquired NMEA information, the module calculates the rest of information data.

Then, a multicast group will be updated with the train info. In this way, if a train component needs this info, it must subscribe to this multicast group to receive it

The geolocation module will also transmit this information to any geolocation on-ground unit that demands it, using unicast UDP. The interface to access to this information from the train is described in Section 3.2.2.4.

The On-board Geolocation Module will be installed in the train PC NUC used by B1 service (see Section 2.3.1.5).

3.2.2.2 Components at the MEC Layer

3.2.2.2.1 On-ground Geolocation Module

The On-ground Geolocation Modules will be installed in the ground PC NUC used by B1 service in the MEC Layer (see Section 2.3.2.4). It is to say, there are two units: one in Spain and other in France

These On-Ground Geolocation Modules receive the train position info updated from the On-board Geolocation Module by demand, even this info will be required with a minimum interval to 0.5 sec.

Any project component that needs to obtain the geolocation info must requested it to the ground module by demand using the interface described in Section 3.2.2.4.

3.2.2.3 Components at the Cloud Layer

There is not any functional block in Cloud Layer for the Geolocation Module.

3.2.2.4 External Interfaces

Interface name	Get interpreted geolocation information				
Protocol	UDP Multicast	Provider	On-board Geolocation Module	Consumer	Any Train component
Input data	None				
Output data	Geographical latitude and longitude Corridor Zone Country Train Speed				
Description	The positioning system will send periodically (period 0.5 sec) to a multicast group the output data				

Interface name	Send raw info through unicast				
Protocol	UDP	Provider	On-board Geolocation Module	Consumer	On-ground Geolocation Modules
Input data	GetAllData				
Output data	Geographical latitude and longitude Zone (These values must be in correspondence with the zone values) Country Train Speed				
Description	The On-board Geolocation Module update the On-Ground Geolocation Modules through UDP datagrams. The info will be updated with a maximum difference of 0.5 sec.				

Interface name	Get interpreted geolocation information				
Protocol	UDP	Provider	On-board Geolocation Module	Consumer	Any On-ground component
Input data	GetAllData				
Output data	Geographical latitude and longitude Zone (These values must be in correspondence with the zone values) Country Train Speed				
Description	The On-ground Geolocation Module update the output data to the project component that requires it. The info will be updated with a maximum difference of 0.5 sec.				

4 Conclusion

D5.2 is a deliverable very close to process on the description of the WP5 components, focused into prepare the integration between them, which is an extremely delicate process, especially in the case of the TGV. SNCF and LFP need to have this information in detail: they have to think about where to physically place the components inside the train, attach them to the train structure, connect them, power them and monitor all possible interferences with existing systems, as these are units in service. In this case, for the information to be useful it must be indicated component by component, each with its different characteristics despite their very different nature (radio units, CCTV cameras, AI or other SW modules).

By extension, components to be installed on the ground are also included, although in this case the type of information needed is different, more oriented to SW components and their interrelation.

D5.2 also emphasis on the software interfaces between all the components. These interfaces are necessary for all partners to develop their own software and to ensure they will all communicate together.

Of course, some modifications will be introduced on these components along the project evolves, due to multiple reasons. That means that this is the current picture of all of them, but successive WP5 tasks (T5.3 for UC3 and T5.4 for UC4) will continue working on this.

It is said that a deliverable is as good as useful is for their users. Note that the beneficiaries of this output are T5.3 and T5.4. Then, the information contained here will be used in successive WP5 deliverables, D5.3 to describe the deployment and validation of UC3 and UC4 on the small-scale testbed, and D5.4 for the large-scale testbed.

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Annex 1 – Details on the TGV

Mechanical characteristics

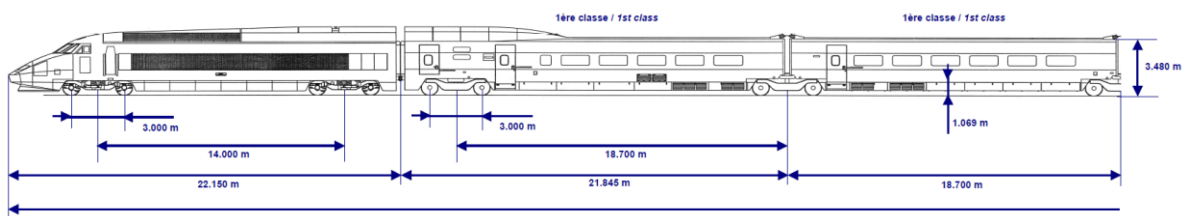
The high-speed train that is planned to be used for large scale trial is a "TGV Réseau". It is a 10 coaches train (8 passenger coaches + 2 cabins).



Figure 34 - picture of the TGV that is planned to be used for large scale trial

Its total length is 200.19m

The Figure 35 gives the length of the different coaches.



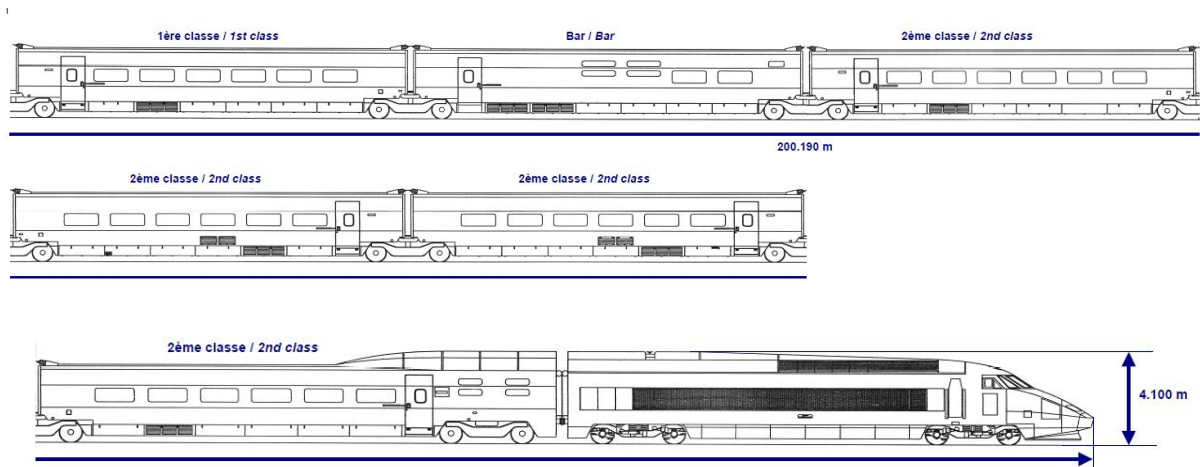


Figure 35 - Characteristics of the TGV that is planned to be used for large scale trial

Power provided to on board devices

The train will allow plugging low power consuming equipments (i.e., laptops) to the existing plugs and SNCF will make power converters available to plug more power consuming devices. These power converters will be directly connected to the train batteries and deliver 220VAC 50Hz through Type E sockets (French type). There will therefore not be any power cut issue during the journeys for the trial for devices powered by the converters.

Available equipment

The train is equipped with some antennas that can be used for the trial for the connection to various receivers/modem:



Figure 36 - GNSS and cellular MIMO2x2 antenna

A GNSS/ MIMO 2x2 cellular antenna: Huber&Suhner 1399.99.0130 (Figure 36)
 This antenna covers frequencies from 694 to 960 MHz and 1350 to 6425 MHz for cellular technologies and 1574 to 1610 MHz for GPS/Glonass. Cellular connectors are female Type N connectors and positioning connector is a male TNC connector.

A MIMO 2x2 cellular antenna: Huber&Suhner 1399.17.0222 (Figure 37)

This antenna covers frequencies from 694 to 960 MHz and 1350 to 6425 MHz. Connectors are female Type N connectors.



Figure 37 - MIMO 2x2 cellular antenna

Annex 2 – Details on LFP Train

LFP train will be used for small scale trial and has the following profile (Figure 38 and Figure 39):

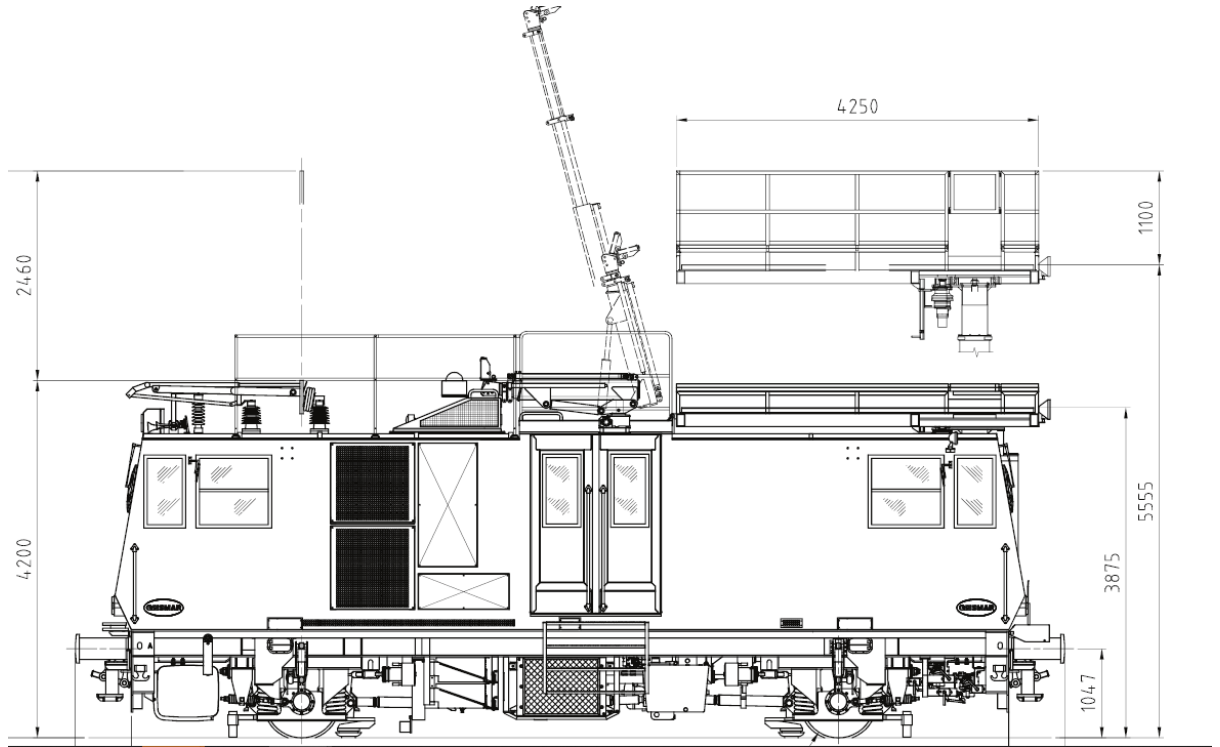


Figure 38 - LFP Train height

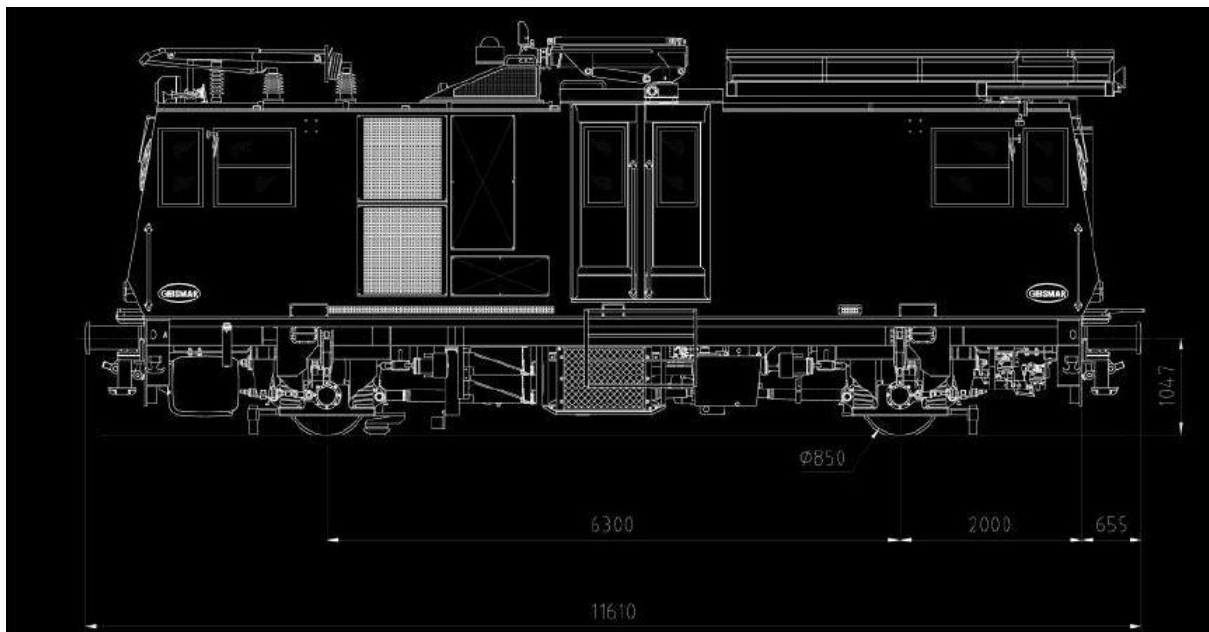


Figure 39 - LFP train length

VLP-16

Real-Time 3D LiDAR Sensor

The VLP-16 provides high definition 3-dimensional information about the surrounding environment.



Specifications:	
Sensor:	<ul style="list-style-type: none"> • 16 Channels • Measurement Range: 100 m • Range Accuracy: Up to ±3 cm (Typical)¹ • Field of View (Vertical): +15.0° to -15.0° (30°) • Angular Resolution (Vertical): 2.0° • Field of View (Horizontal): 360° • Angular Resolution (Horizontal/Azimuth): 0.1° – 0.4° • Rotation Rate: 5 Hz – 20 Hz • Integrated Web Server for Easy Monitoring and Configuration
Laser:	<ul style="list-style-type: none"> • Laser Product Classification: Class 1 Eye-safe per IEC 60825-1:2007 & 2014 • Wavelength: 903 nm
Mechanical/ Electrical/ Operational	<ul style="list-style-type: none"> • Power Consumption: 8 W (Typical)² • Operating Voltage: 9 V – 18 V (with Interface Box and Regulated Power Supply) • Weight: ~830 g (without Cabling and Interface Box) • Dimensions: See diagram on previous page • Environmental Protection: IP67 • Operating Temperature: -10°C to +60°C³ • Storage Temperature: -40°C to +105°C
Output:	<ul style="list-style-type: none"> • 3D LiDAR Data Points Generated: <ul style="list-style-type: none"> - Single Return Mode: ~300,000 points per second - Dual Return Mode: ~600,000 points per second • 100 Mbps Ethernet Connection • UDP Packets Contain: <ul style="list-style-type: none"> - Time of Flight Distance Measurement - Calibrated Reflectivity Measurement - Rotation Angles - Synchronized Time Stamps (µs resolution) • GPS: \$GPRMC and \$GPGGA NMEA Sentences from GPS Receiver (GPS not included)

63-9229 Rev-H

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1. Typical accuracy refers to ambient wall test performance across most channels and may vary based on factors including but not limited to range, temperature and target reflectivity.
 2. Operating power may be affected by factors including but not limited to range, reflectivity and environmental conditions.
 3. Operating temperature may be affected by factors including but not limited to air flow and sun load.



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