A public-private organisation for innovation projects

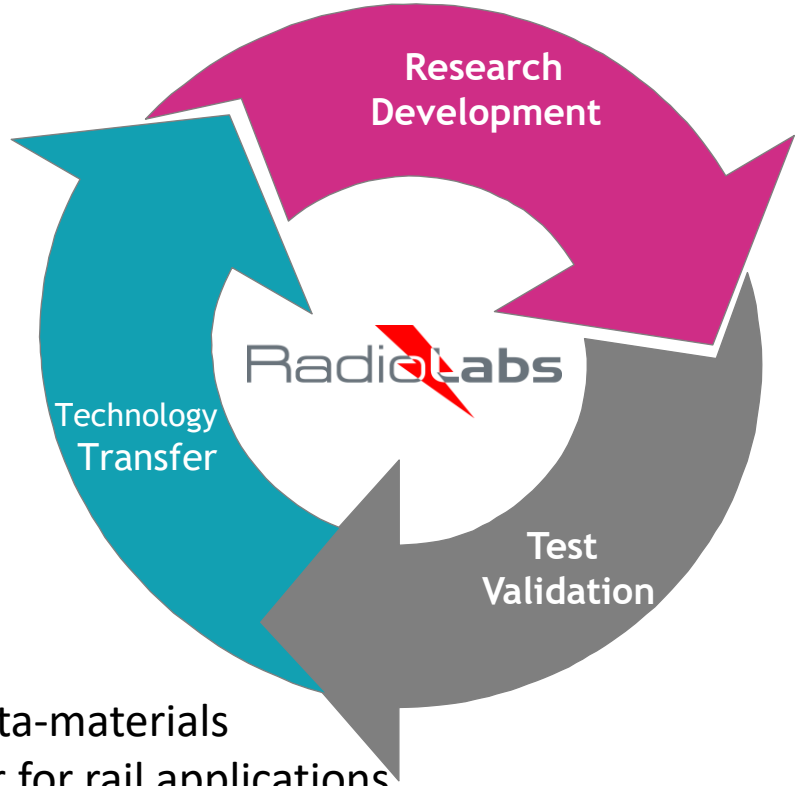
Profile & Expertise

July 2025

Who we are

We are a public-private entity for Research, Innovations and Technology transfer

- ❑ created in 2001 as consortium between universities and industries
- ❑ *non profit organisation*
- ❑ SME status
- ❑ members of the consortium are three universities, Roma-TRE, Roma Tor Vergata, L'Aquila and three industries, Hitachi Rail STS, Intecs, and Cegeka



Organisation & Governance

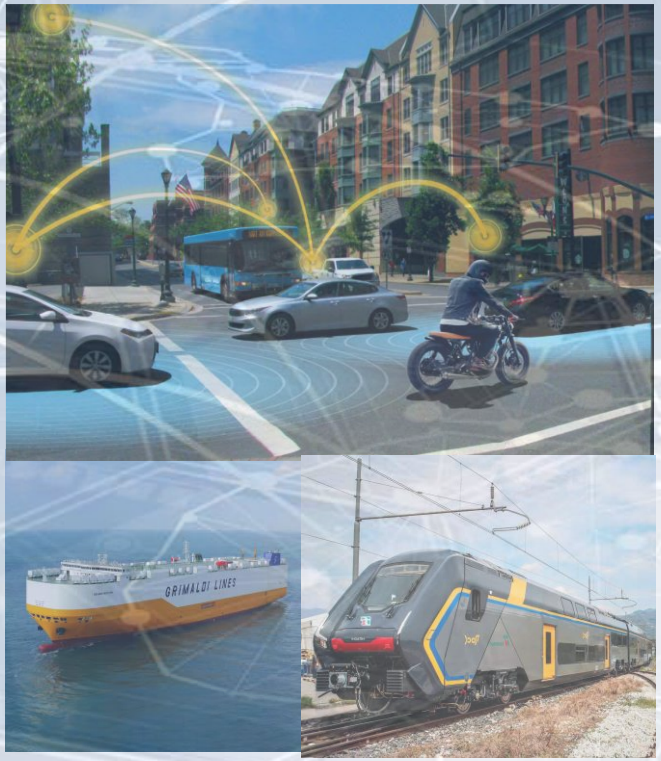
- 15 highly skilled resources, MD, PhD
- President, Vice-President, Technical Director are full professors
- Scientific commette
- Board of directors: 2 representatives for each member with equal vote right
- Three specialised laboratories at each of the three Universities
  - ➢ Roma TRE Research on Multi-sensor positioning, Phased array antennas with meta-materials
  - ➢ Roma Tor Vergata: Research on Multi-bearer telecom based on Satcom & Cellular for rail applications
  - ➢ L'Aquila: V2X, V2I Telecom, Virtual Testing, Cybersecurity, Connected –autonomous car applications
- Turn-over 2024: 1.37 M€
- Scientific pubblications on international journals and conferences collected about 500 citations

RadioLabs

Vision

The 3S priorities:

- Vehicle positioning with Safety proof
- Sustainability leveraging on a mix of technologies including satellites
- Synergy between rail, road and maritime technologies for autonomous driving



Mission

Applied Research, Innovation and Knowledge Sharing in the emerging fields of ICT

Support for young Graduates PhD Students, PostDocs, through scholarships, awards internship

Preparing for the digitalisation of transportation

RadioLabs

Main Research areas

- Next Generation Communications
  - Integration of SATCOM into 5G and 6G
  - Low Latency Multi-Access Edge Computing
- Secure Communications
  - State of the Art Crypto Engine
    - NIST Elliptic Curves
    - Post Quantum Computing NIST Encryption

Our competences

High Accuracy, High Integrity Positioning For Automating Transportation Systems

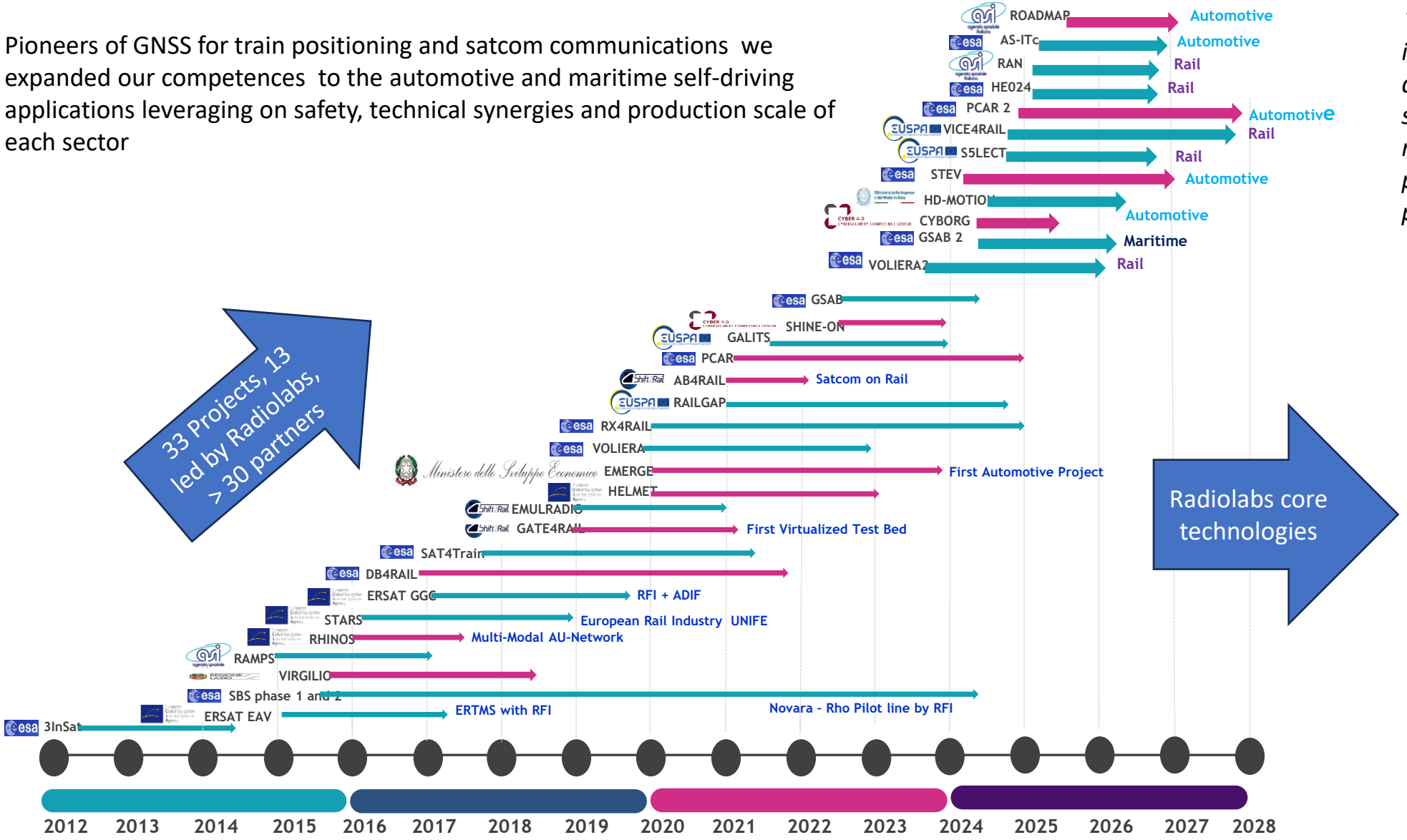
Multi-Sensor Positioning

AI-based connectivity platform to use cellular-satcom networks

Laboratories to simulate, test and validate new technologies for safety critical operational scenarios

Multi-year Research & Innovation plan

Pioneers of GNSS for train positioning and satcom communications we expanded our competences to the automotive and maritime self-driving applications leveraging on safety, technical synergies and production scale of each sector



33 Projects, 13 led by Radiolabs, > 30 partners

Radiolabs core technologies

"EU needs to build its own industrial capacities for connected and automated vehicles to use space-based data and services for navigation, high precision positioning, secure connectivity provided by Galileo/EGNOS/IRIS"*

- High integrity positioning
- Satcom & public Telecom
- Cybersecurity
- Testing & Validation

* Brussels, 5.3.2025 COM(2025) 95 final

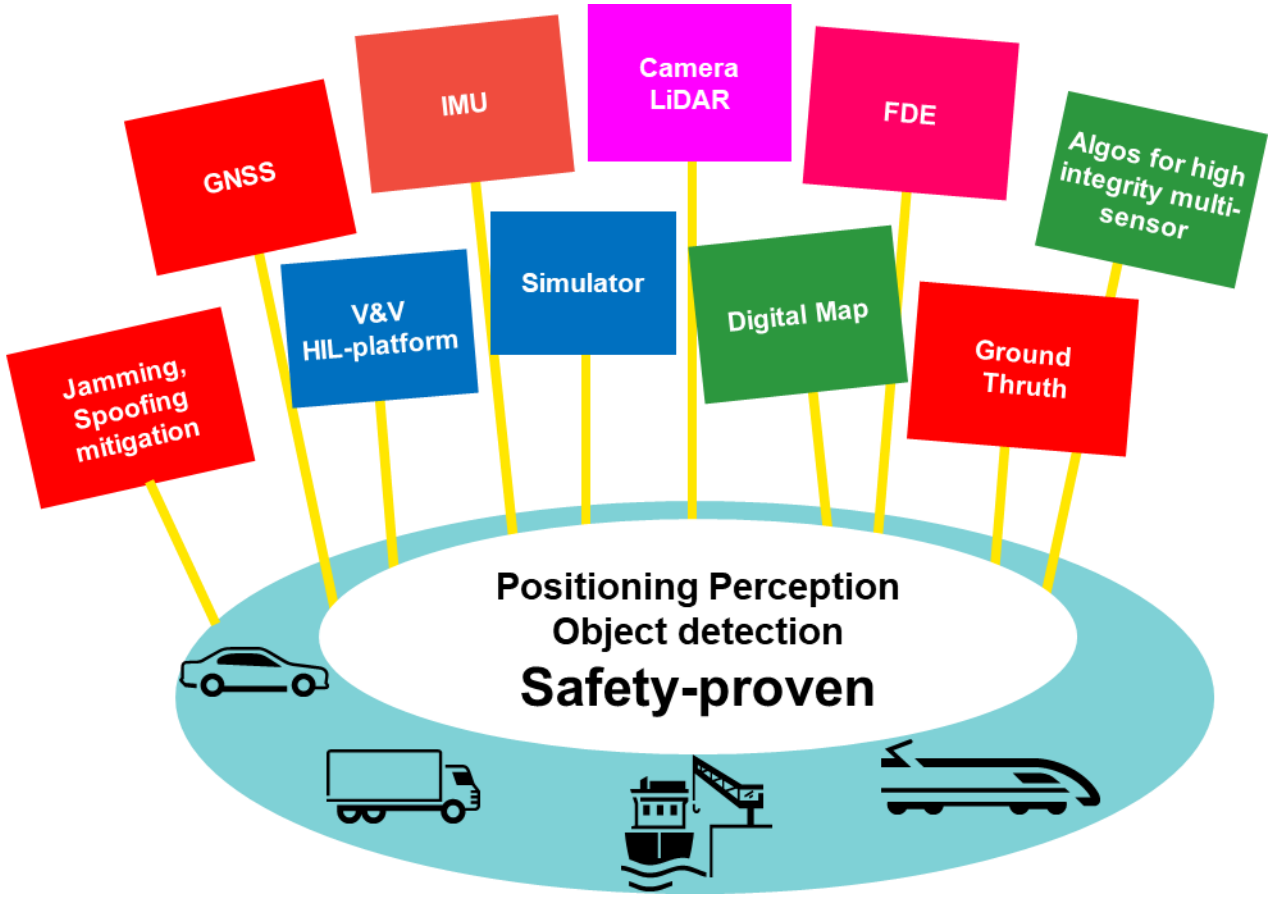
Core Technologies

- High integrity positioning
- Satcom & public Telecom
- Cybersecurity
- Testing & Validation

GNSS-based multi-sensors for high integrity positioning & perception

The digitalisation of the transports relies on the availability of accurate geo-localization to guarantee the vehicle's positioning everywhere with high integrity and safety. GNSS absolute positioning is complemented by other sensors leading to multi-sensors application-tailored solutions.

Our capabilities spans the entire innovation lifecycle to guarantee the safety, competitiveness, compliance to standard and more importantly the independency in a sector crucial for the economy, know-how and job creation



A plan for 2-Tier Augmentation Network for Rail and Automotive

The goal is to use EGNOS, GALILEO, HAS and Local networks

1. 2012 — 3INSAT — 2 Tiers Architecture using EGNOS
2. 2015 — ERSAT — Assessment & safety proof
3. 2016 — RHINOS — ARAIM for Rail
4. 2020 — HELMET — Rail & Automotive
5. 2025 — **RAN:** Prototype and Test a national system

All-in-one infrastructure providing incremental services with the latest technologies DGNSS, NRTK, PPP-RTK RTCM SC-104 and SC-134 standards

[HELMET - Satellite technologies for autonomous, connected and ecosustainable transport | Radiolabs]

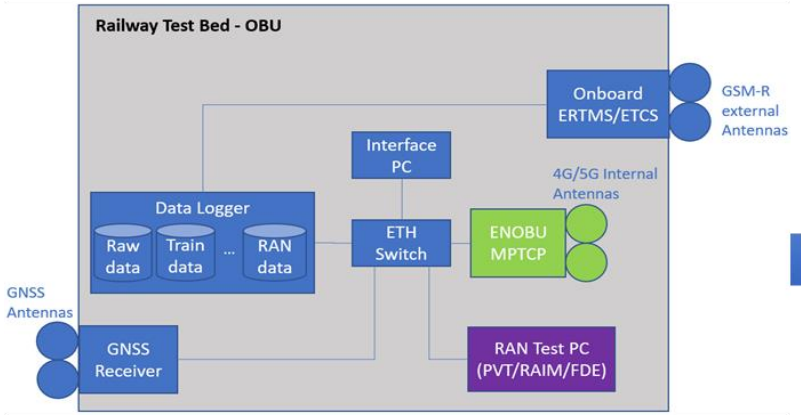
RAN - Rete di Augmentation Nazionale

Development and prototyping of an Augmentation Network for Rail and Automotive applications

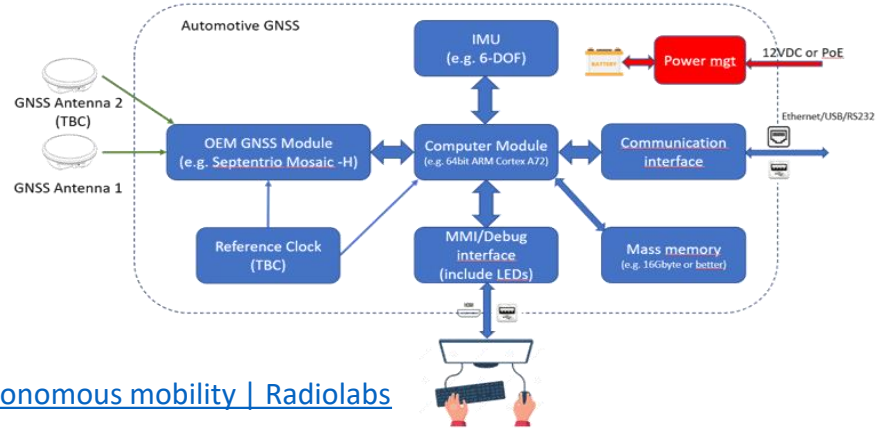
Liaison with Europe's Rail FA6 FutuRe project

- Multi – tiers architecture: EGNOS + Local networks
- National coverage
- ERTMS and CCAM applications
- Compatible with COTS receivers RTCM SC-104, 134
- Demo tests for Rail & Automotive applications
  - **RAIL: EGNOS only, AU-messages using a FRMCS channel**
  - **RAIL & Automotive: 2-Tier AU-network (EGNOS + Local)**

- **Rail - ERTMS**



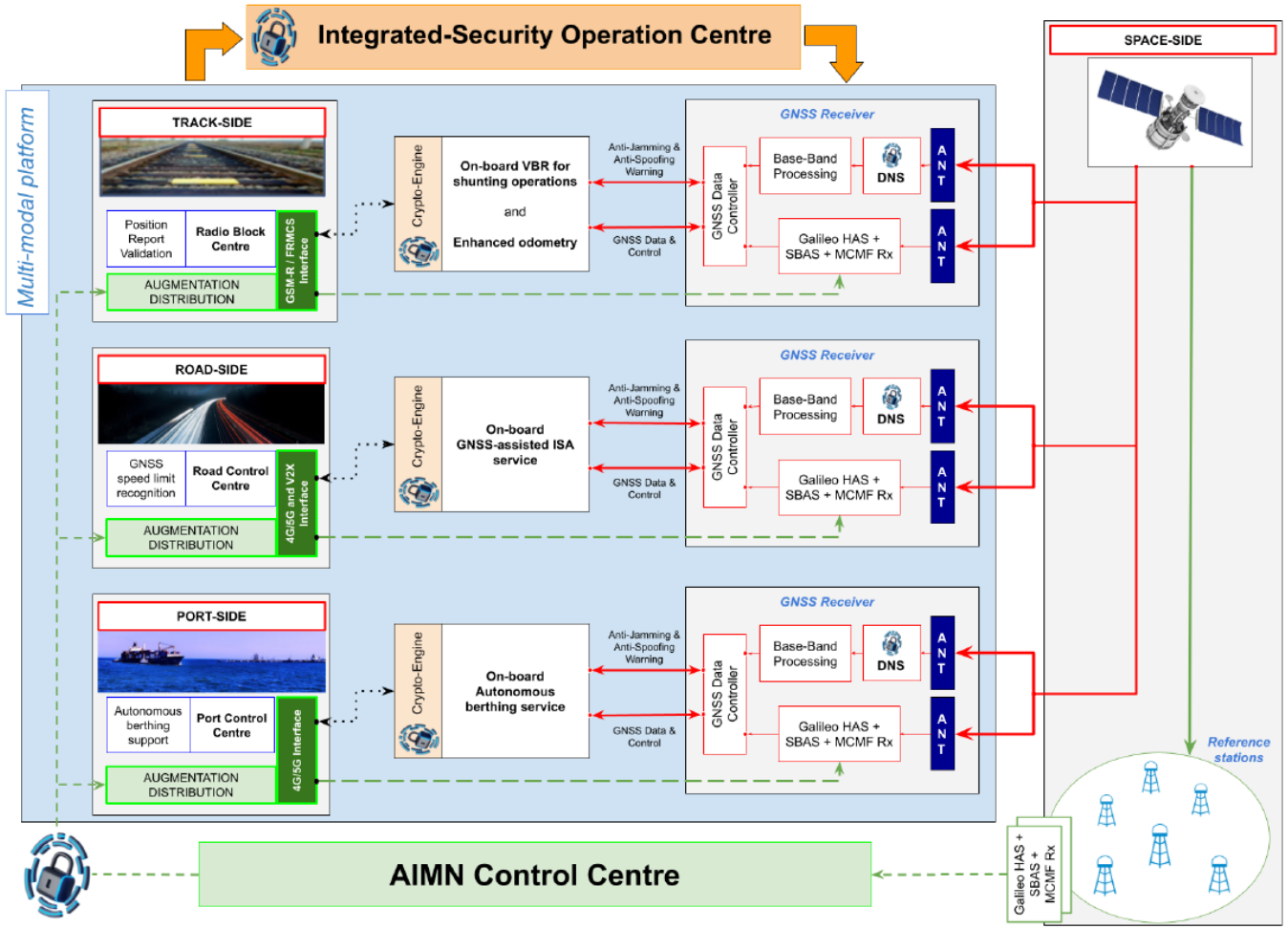
- **Automotive** - CCAM-Smart Roads



[Radiolabs partner of the national augmentation network for autonomous mobility | Radiolabs]

Multi-modal augmentation network for different services

Focus on Resiliency proof: make the multimodal augmentation network and consequently the entire EGNSS-based positioning system robust and resilient against potential cyber-attacks

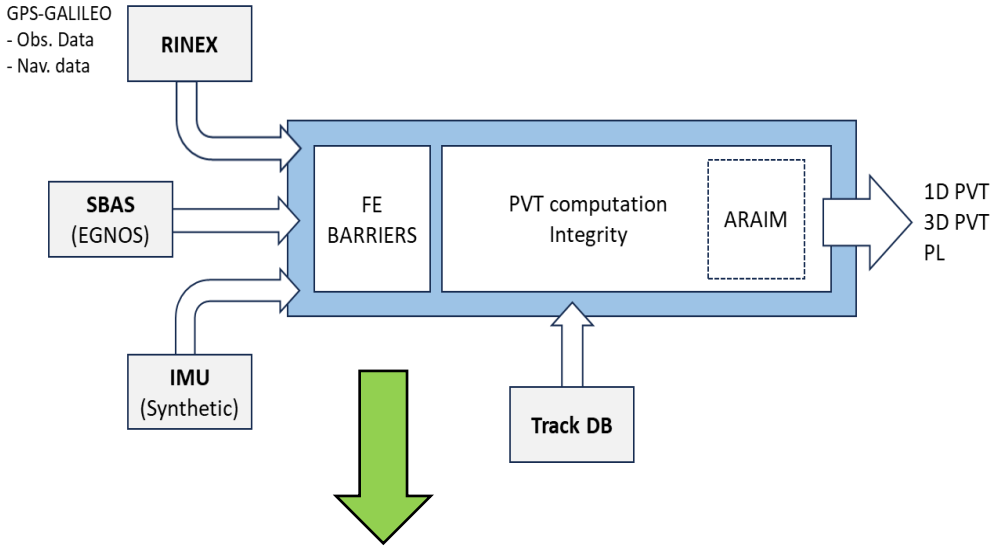


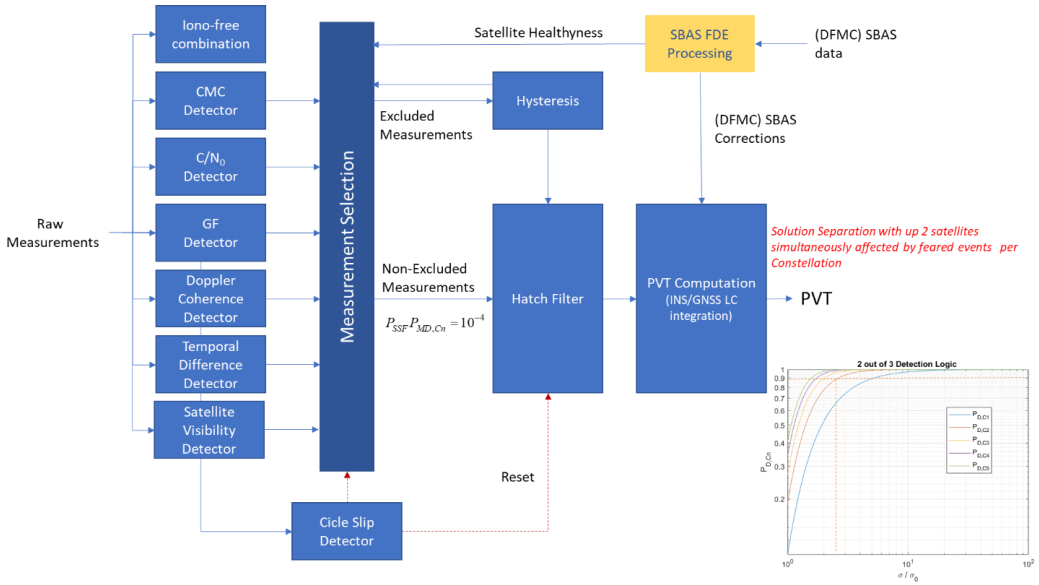
Radiolabs multimodal-secure GNSS augmentation network architecture supports multiple Service Levels (SLs), where each SL satisfies a set of requirements linked to specific rail, automotive and maritime. High accuracy and integrity positioning. SBAS and Local Networks are combined in two-tiers to elaborate corrections for the on-board positioning system

Service Level	Augmentation	95% Accuracy	$1 - 10^{-7}$ Protection Level
1(a)	DF GPS + Galileo SBAS (EGNOS)	0.3 – 1.0 m	5 – 25 m
1(b)	(add) DF LADGNSS	0.15 – 0.4 m	2.5 – 10 m
2	(add) PPP-AR	0.02 – 0.10 m	0.5 – 2.5 m
3	(add) RTK/NRTK	0.01 – 0.05 m	0.2 – 1.0 m

HELMET - Satellite technologies for autonomous, connected and ecosustainable transport | Radiolabs

Geo-Localization platform with FDE for ERTMS Train control system





Novel **PVT engine** using GPS, GALILEO, EGNOS, IMU, dual frequencies together with SS-ARAIM processing for feared events mitigation to ensure a train positioning estimation with the required integrity and accuracy

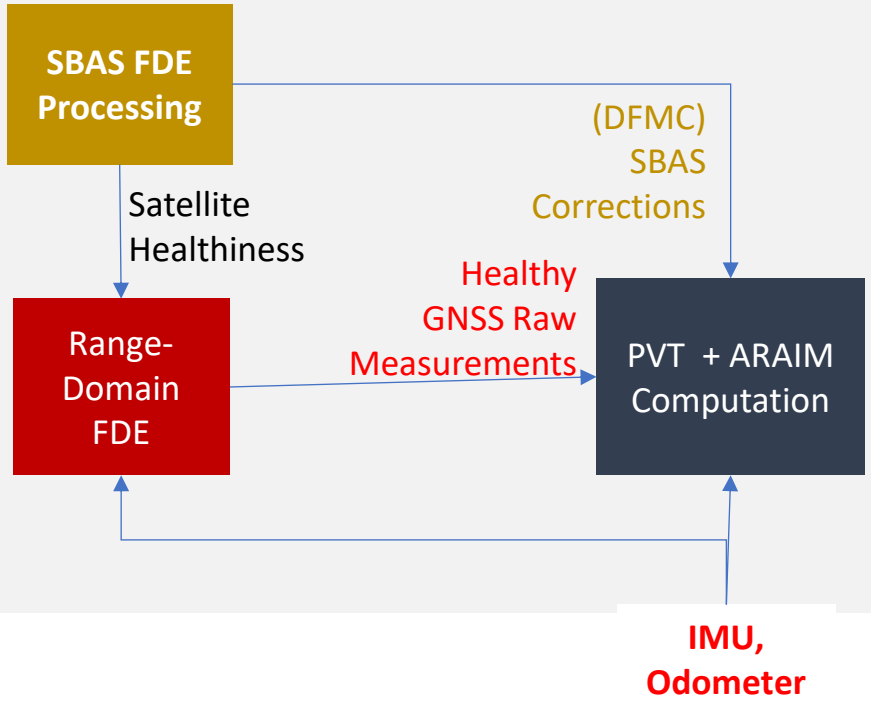
Mitigation techniques against feared events

- Ionospheric Free Combination
- Carrier smoothing of pseudorange measurements

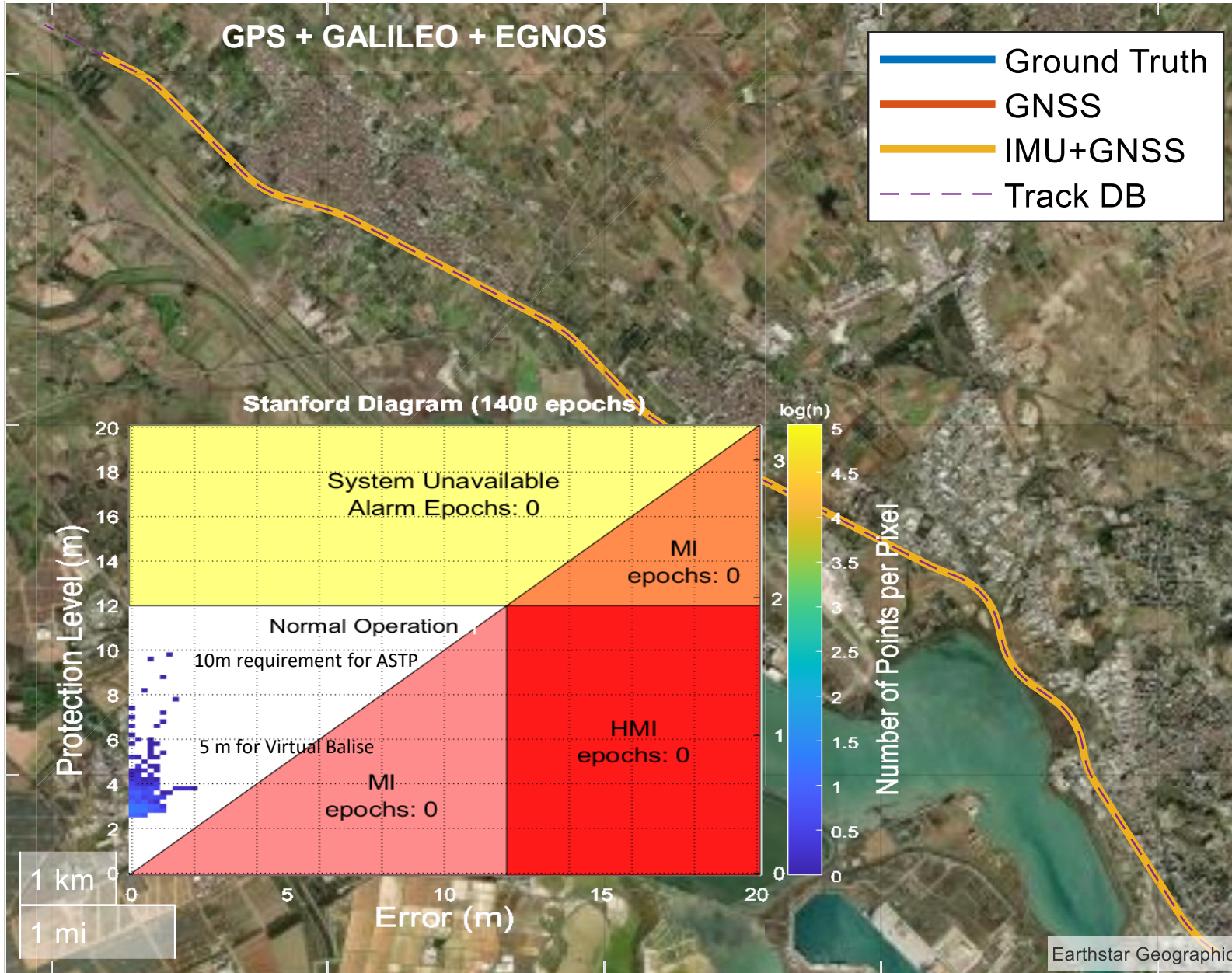
FE Barriers

- Iono-free Code Minus Carrier Monitor
- Geometry Free Combination Monitor
- Signal to Noise Ratio Indicator
- Doppler Coherence Indicator
- Satellite Visibility Detector

Geo-localization performance for the ERTMS train positioning

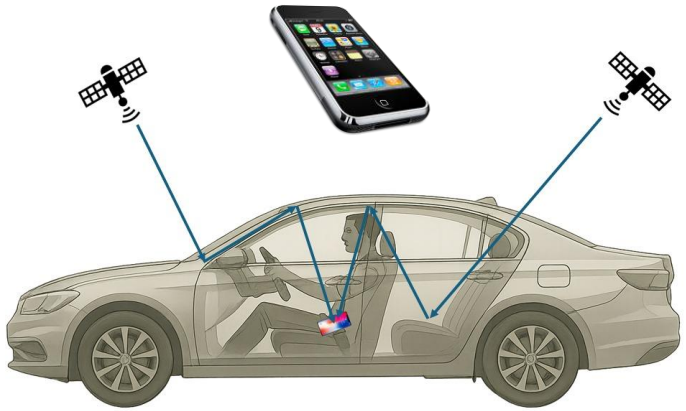


Our new GNSS-IMU Positioning platform is compatible with the virtual balise application and the requirements of the Advanced Safe Train Positioning ASTP device.



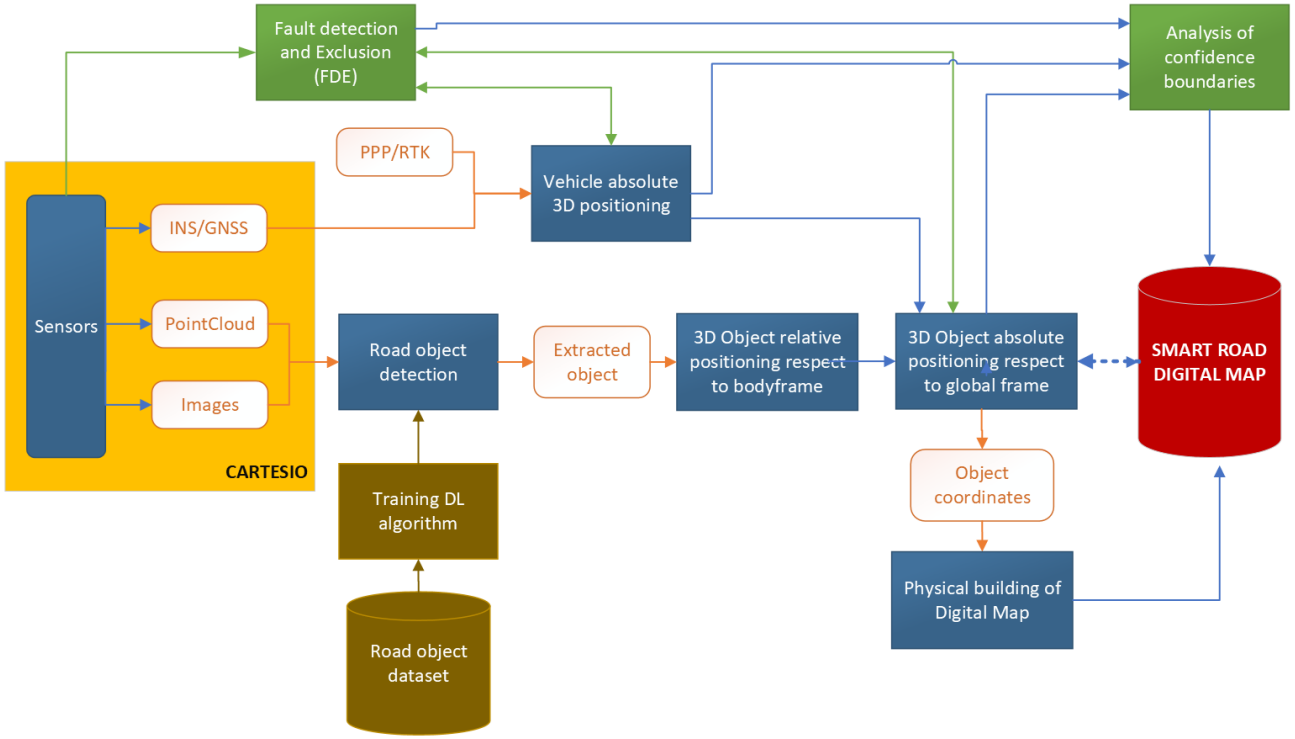
GNSS, Video sensors, Digital maps for smart road safety critical applications

High accuracy - integrity positioning based on GNSS-RTK and smart phones



Intelligent Speed Assistance (ISA) with GNSS-Digital Map, Video

Platform for the production of high integrity digital maps

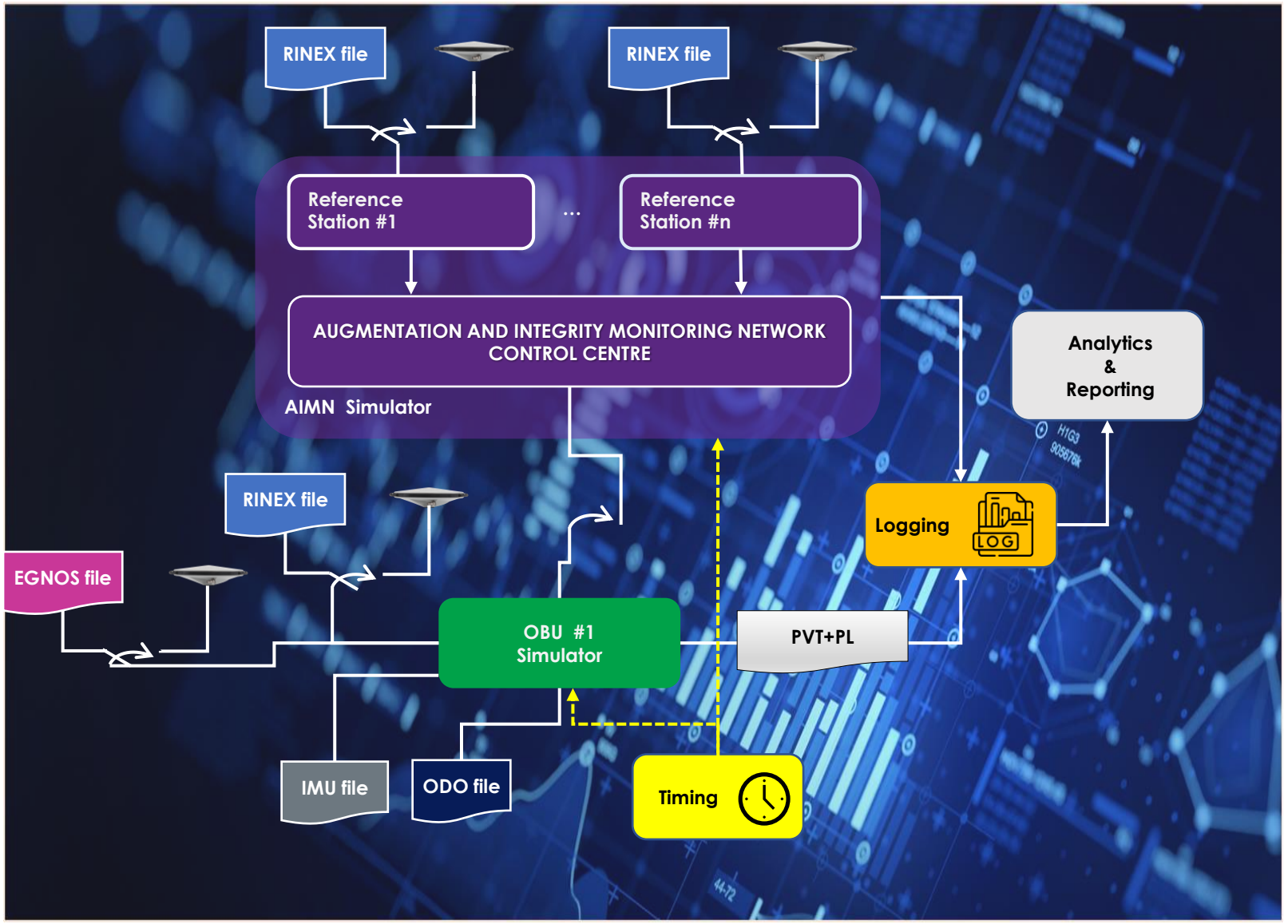


On road data acquisition	Data processing for digital map provisioning

VIRGILIO – High Fidelity Simulator for GNSS-based multi sensor positioning systems

EGNOS-Galileo-Dual Frequency ready
cloud-based architecture

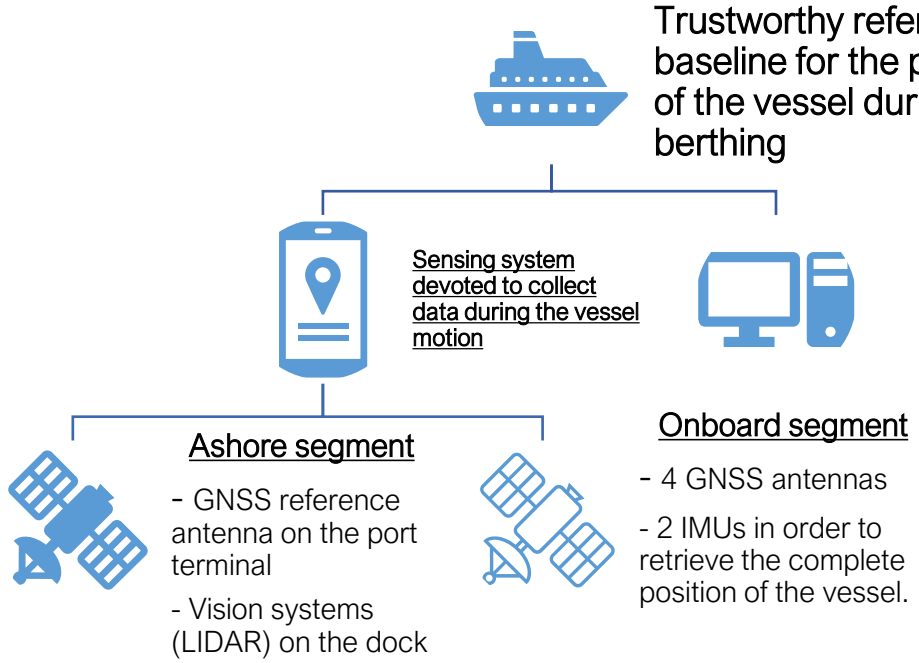
VIRGILIO is a digital environment entirely developed by Radiolabs to simulate with H/W in the loop the performance of GNSS-based multi-sensor positioning solutions – including Augmentation networks - for safety-critical rail, road and maritime applications. The performance of VIRGILIO, for the most stringent safety requirements SIL-4 of the ERTMS, have been validated through the MAAST (MatLab Algorithm Availability Simulation Tool) of the Stanford University GPS Laboratory within a cooperation with Radiolabs and also by several intensive test campaigns



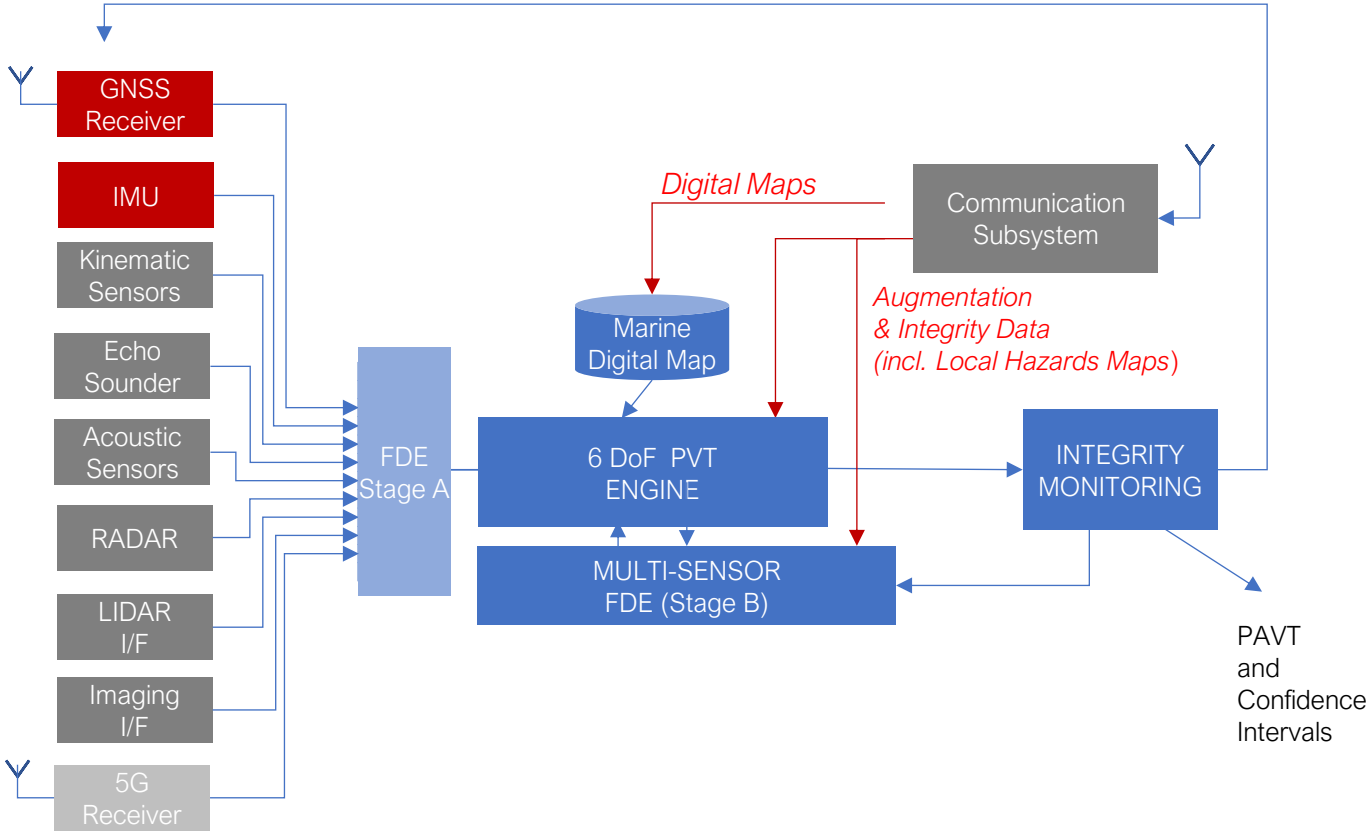
Geo-localization with high accuracy-integrity for autonomous ship berthing

Grimaldi Satellite Assisted Berthing

Trustworthy reference trajectory

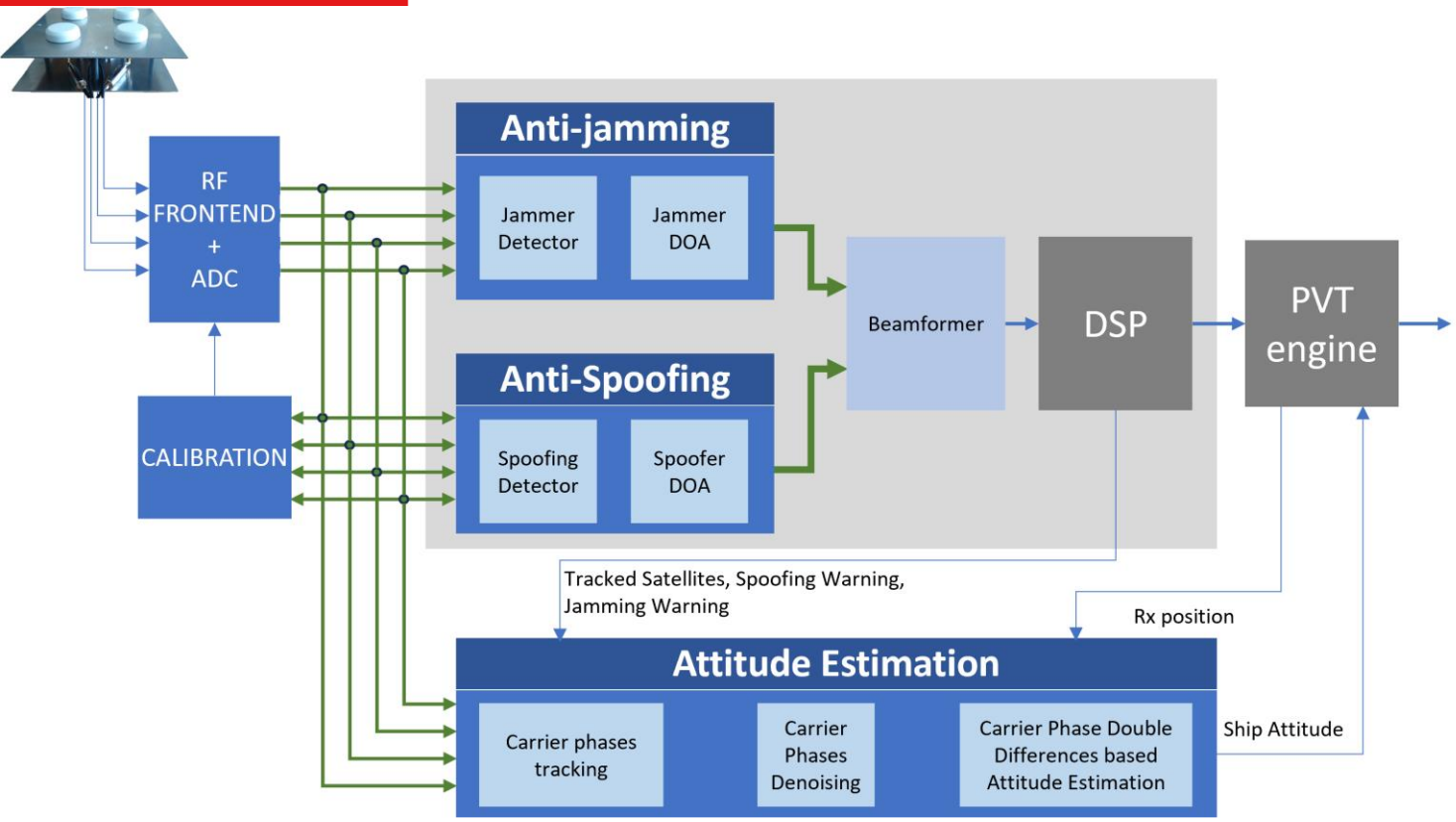


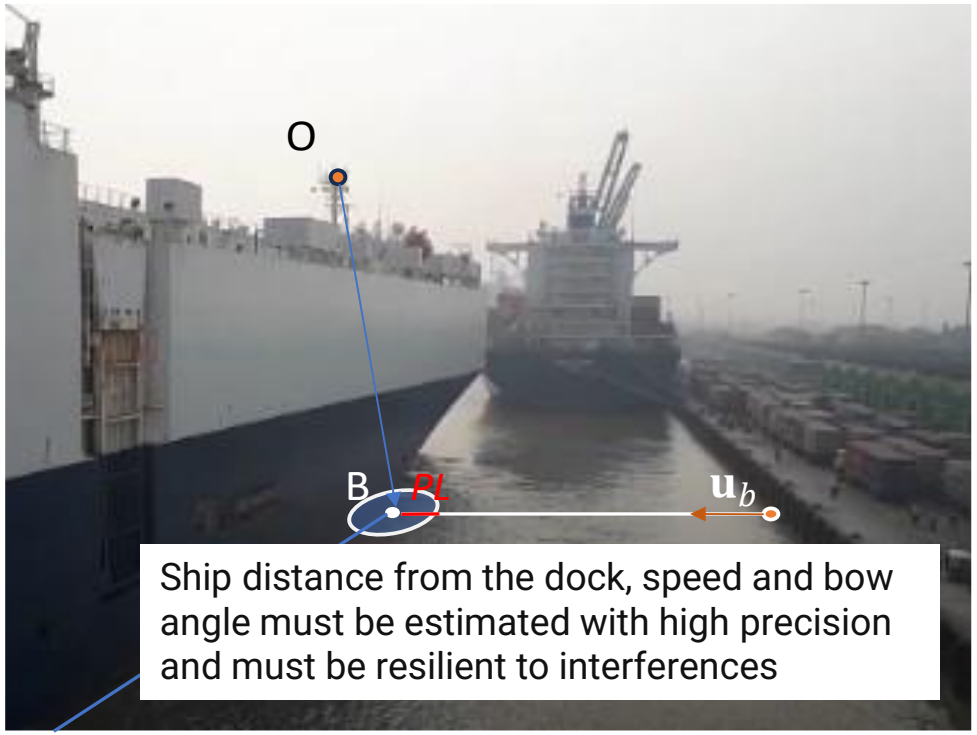
Geo-localization platform



The trustworthy reference trajectory is an indispensable tool to assess the performance of the ship geo-localization system to guarantee compliancy with safety requirements and minimisation of the risk of possible damages from excessive positioning, speed and bow angles estimation and possible interferences. Radiolabs is co-prime contractor of the GSAB project led by Grimaldi [Radiolabs partner of Grimaldi for the GSAB project | Radiolabs]

High accuracy and secure positioning for Assisted Berthing systems



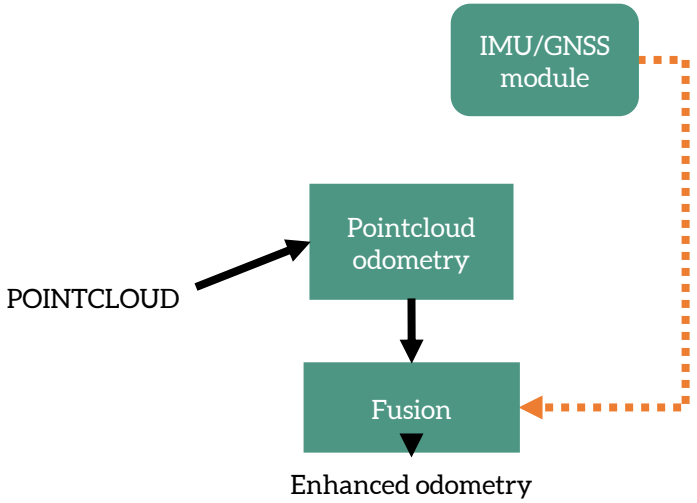


The signals of the antennas are demodulated using the same oscillator, clock, and a common carrier phase tracking loop. So far signal differences eliminate the need to solve both phase ambiguities and receiver clock signal errors, with a drastic increase of the navigation data availability. Moreover, the use of a common digital loop for carrier phase tracking reduces the probability of having a misleading information due to cycle slip. In addition, high rejection of interference signals, including jamming and spoofing, is provided. The GNSS receiver is the evolution of the Digital Beamforming developed for rail applications

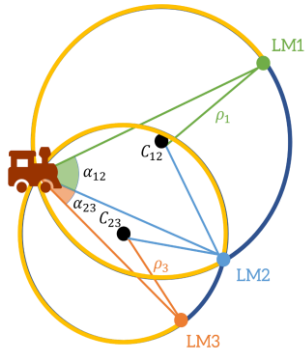
Use of GNSS, Video, LiDAR sensors for train applications

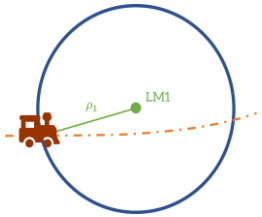
Track Discrimination

Enhanced Odometer



3D & 1D Positioning

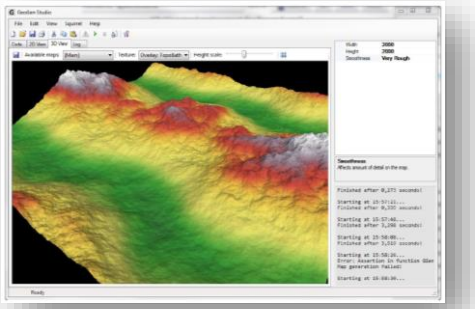


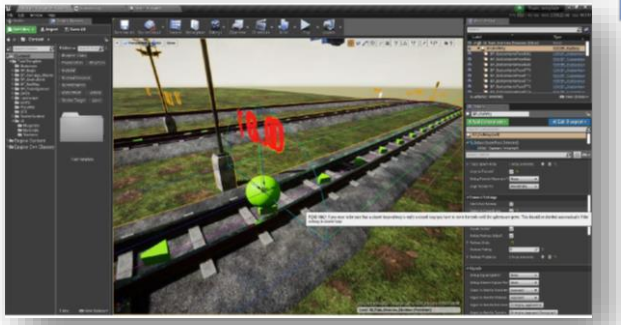


- **Track Discrimination**– Responsible for discriminating the Track in view where the train is located.
- **Enhanced Odometer** – Providing odometer information with performances better than those described in Subset 041 ISSUE 3.2.0.
- **1D and 3D Position**
  - **1D position** information is the estimated relative position on the track of the Train
  - **3D position** information is the estimated position information when the track has not been discriminated yet or the localization is totally unknown (e.g. start-up).

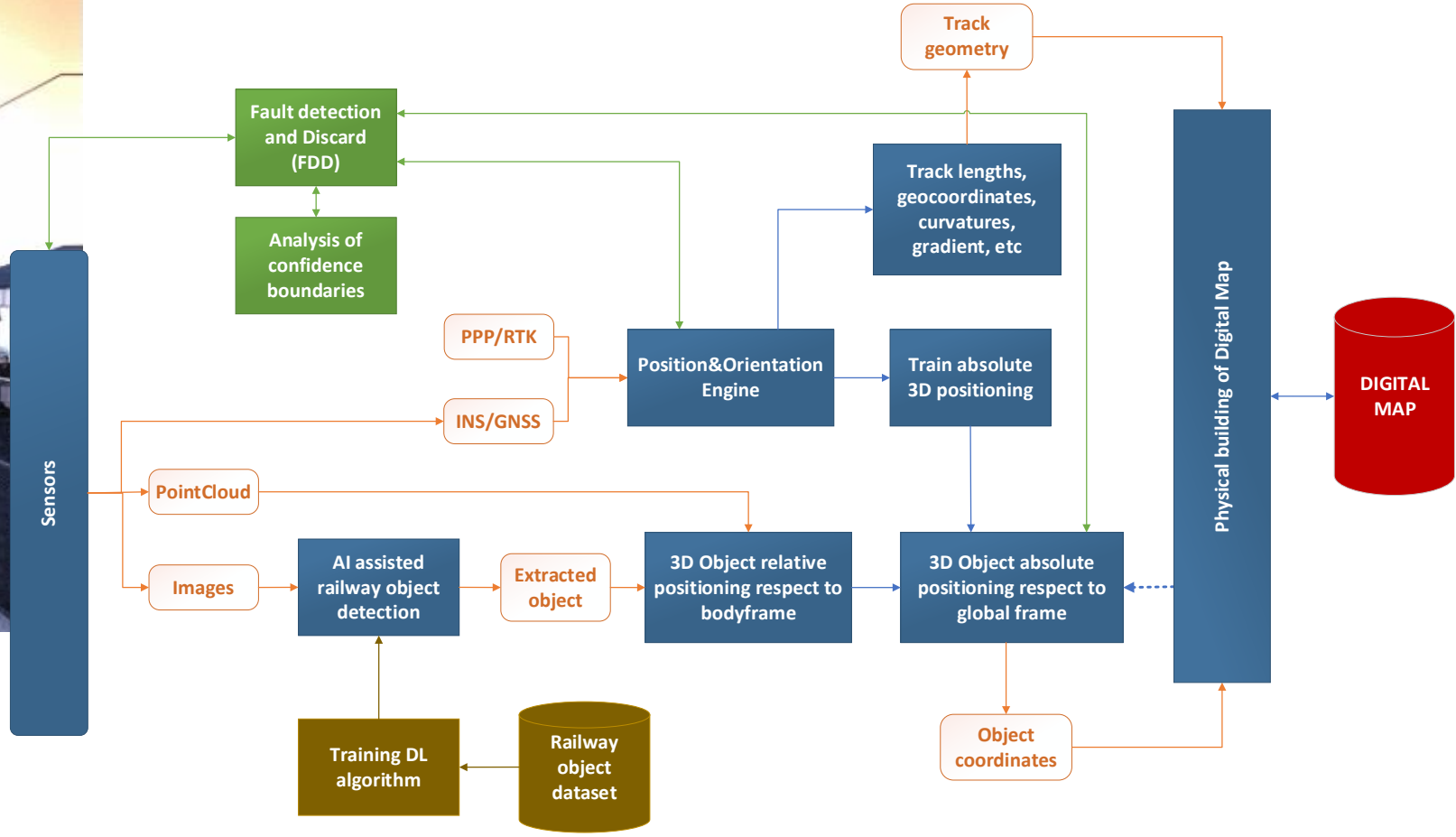
[Go ahead to VOLIERA-2 project | Radiolabs]

Virtual environment for digital twin of rail scenarios





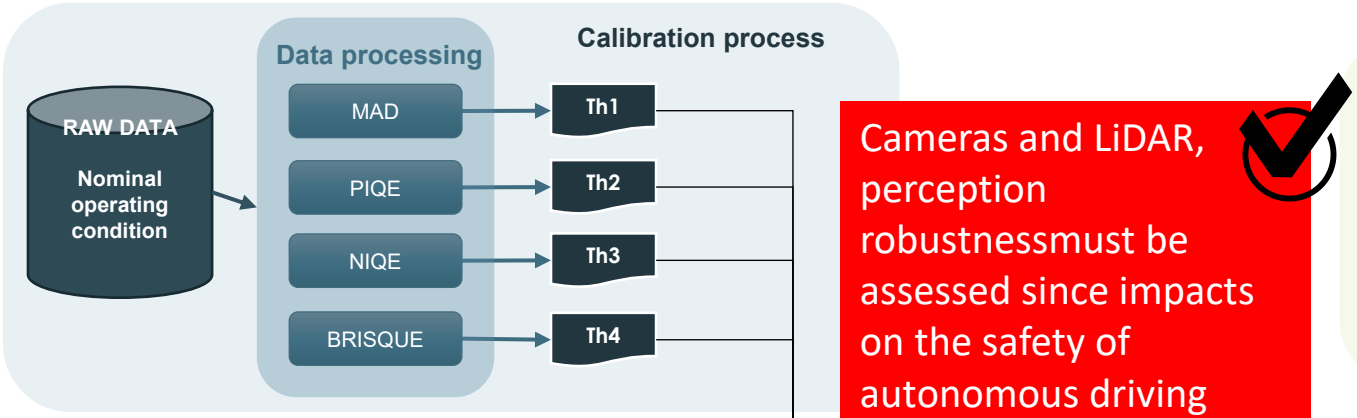
Digital maps



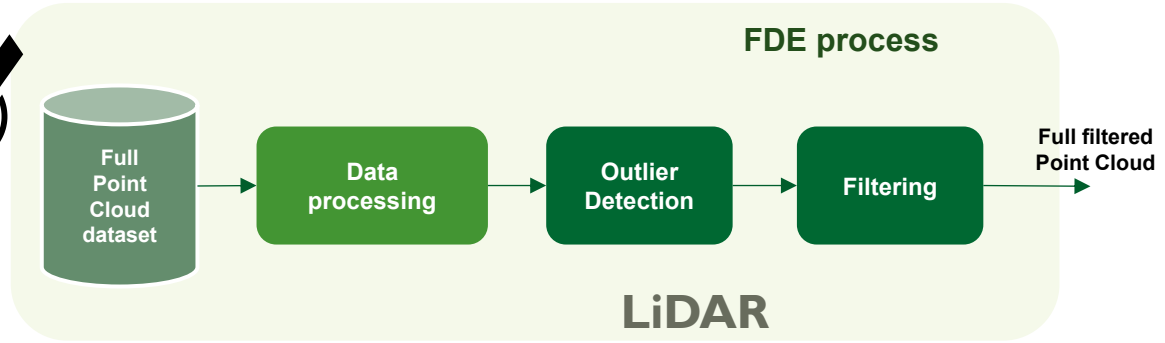
- GNSS + Visual + LiDAR
- Computer vision on Deep Learning

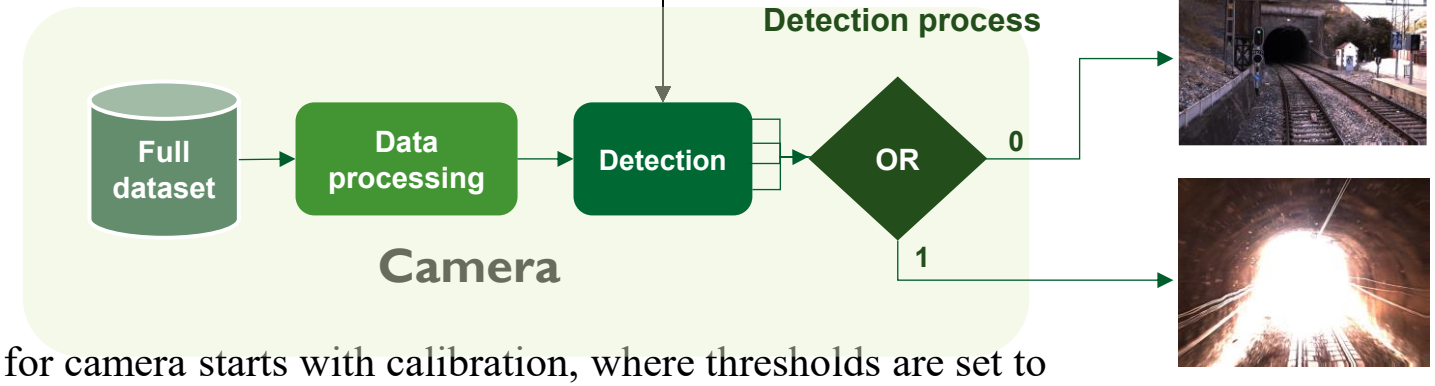
[Digital maps and object recognition for GNSS-based | Radiolabs]

FDE process for Camera and LiDAR



Cameras and LiDAR, perception robustnessmust be assessed since impacts on the safety of autonomous driving systems

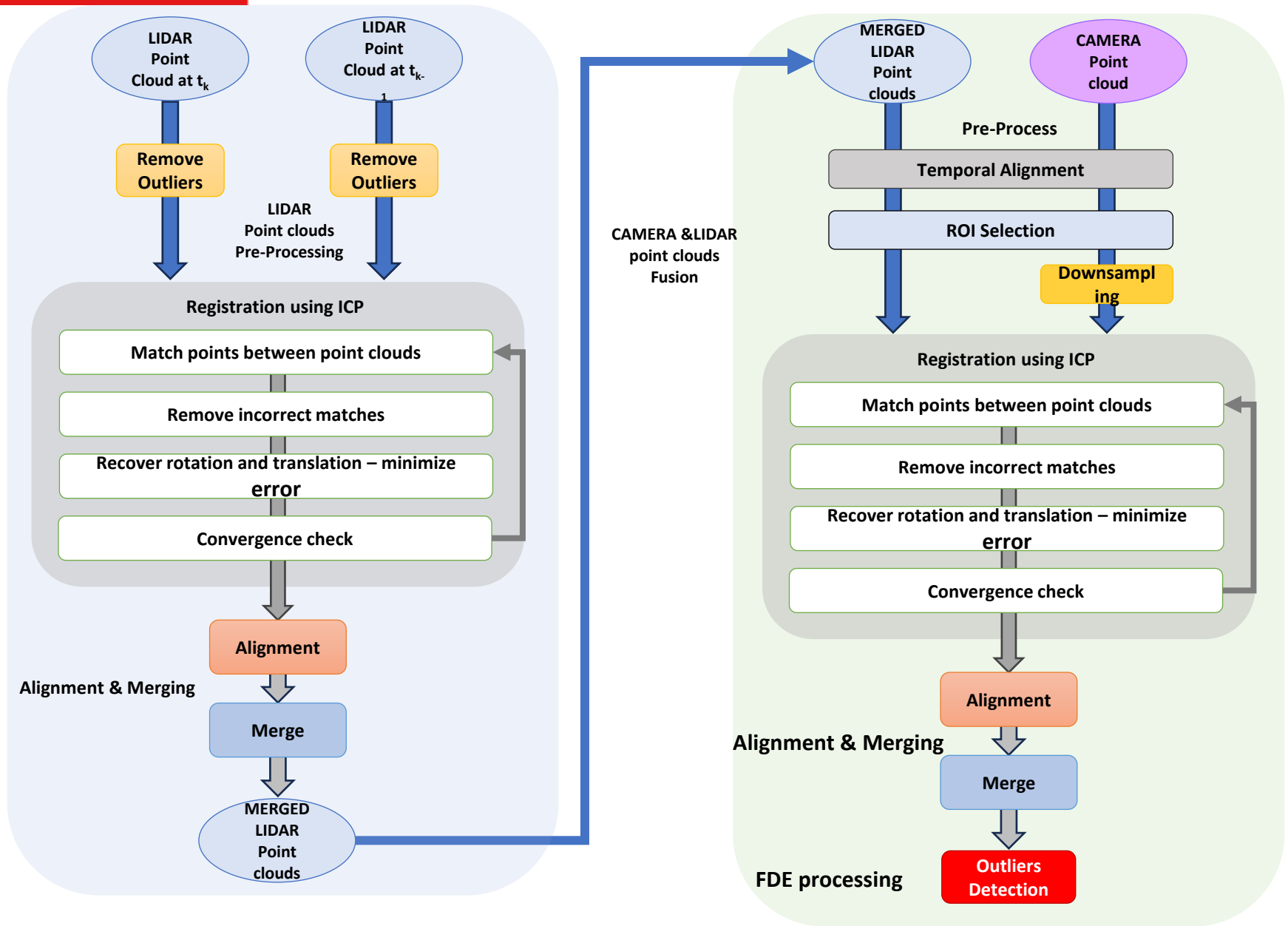




FDE for camera starts with calibration, where thresholds are set to determine image quality based on the mean and standard deviations of the above four KPIs. Next is the detection phase, where the dataset is tested against these thresholds. Images scoring below the thresholds are marked as "good," while those above are "bad." The final detection results are computed using an OR operation on each image quality evaluator's results.

FDE applied to LiDAR data are to enable the identification and mitigation of sensor faults and prevent the faults from reaching the processing stage. Sensors' data is individually assessed to remove outliers. Detecting and discarding faulty data in LiDAR point clouds is crucial for ensuring the accuracy of 3D environmental models. Point clouds often contain noise and outliers, especially in large-scale or rugged terrain scenarios.

FDE for a Camera-LiDAR sensor fusion solution



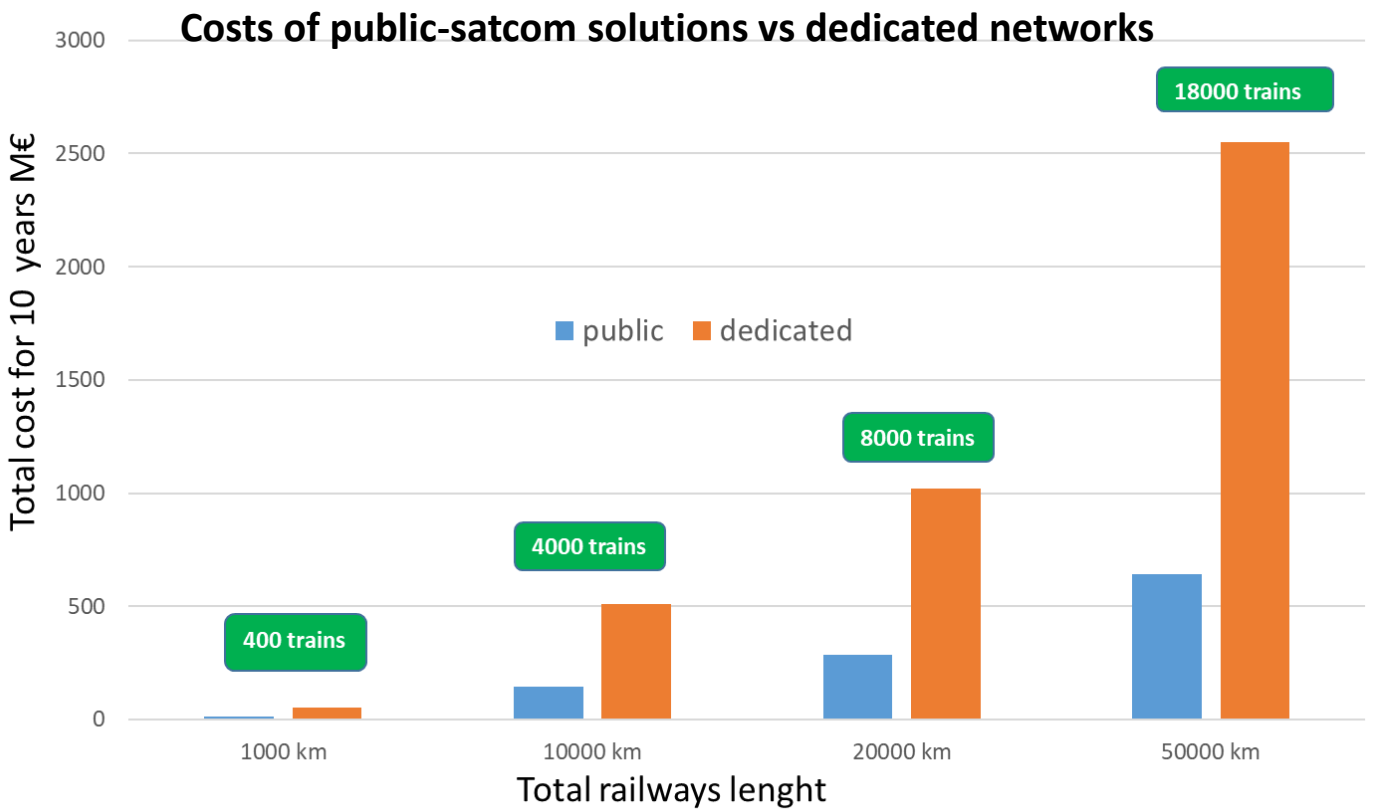
Camera-based methods leverage feature tracking and visual odometry for localization but are sensitive to illumination changes and occlusions. LiDAR-based approaches rely on geometric features and point cloud registration but struggle in textureless environments and suffer from drift. Both modalities degrade under challenging environmental conditions: cameras suffer from poor contrast and occlusions, while LiDAR returns become sparse or noisy due to scattering and absorption. The fusion of these two modalities enhances perception robustness by mitigating individual sensor limitations, thereby enabling more accurate and complete mapping of railway environments

Core Technologies

- High integrity positioning
- Satcom & public Telecom
- Cybersecurity
- Testing & Validation

Pioneering Satcom & Terrestrial Telecom Networks for Rail Applications

The growth of cellular and satellite telecom systems with the 5G and broadband mobile satellites are creating a global and pervasive telecom infrastructure offering connectivity services in any place of the world. Furthermore, 5G will provide millisecond latencies and network “slicing” capabilities that are ideal to realize bespoke virtual networks. Satcom constellations of small satellites in low earth orbits are delivering internet access globally with latency comparable to fiber optics without building a dedicated infrastructure



3GPP Release 17+ NTN: Direct-to-Device Satellite

Release 17 allows direct access to satellite with standard mobile phones opening the way for the interoperability among different networks that can be used overcoming the distinction between satellite and terrestrial access with seamless roaming capabilities between the two segments This standard allows today data rate up to tens of kilobits anticipating Releases 18 and 19 that will allow higher data rates and better performance with on board processing satellite payloads, ensuring global connectivity

CR20036FU1.pdf

Radiolabs leading a study on emerging telecom bearers for railways | Radiolabs

Multi-bearer Capabilities already Validated

Multi-bearer network with same KPI and resiliency of dedicated networks already tested with RFI in Sardinia and other projects

Cellular

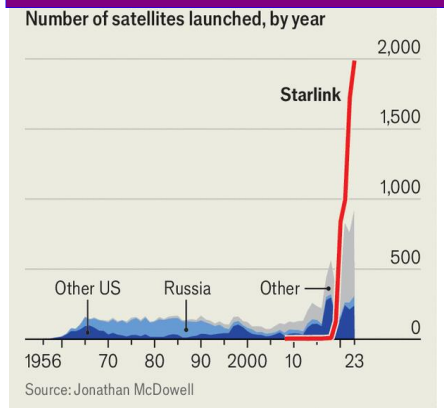
World standard
Multi operators
High capacity

Satcom

Global coverage
pre-emption
capability

Building a bearer independent solution

- Service based model: pay per use
- Quality of Sevice can be guaranteed
- No need for a dedicated - permanent infrastructure
- Ready to use
- Reduction of CO2 emission

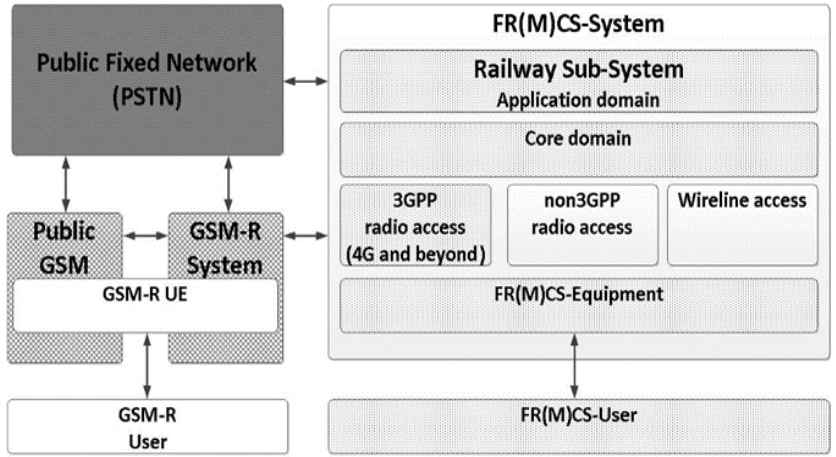


Reference The Economist

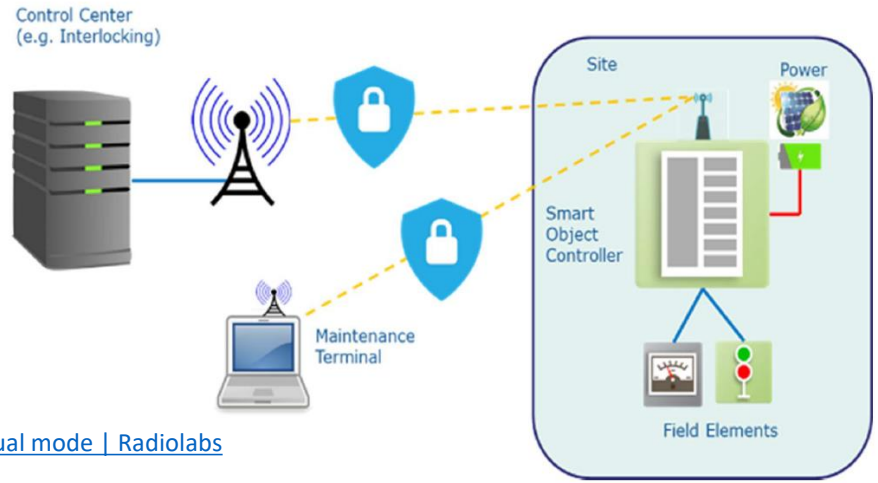
Starlink opened a new era with + 7000 sat in orbit and new ones to allow smartphones to connect to sat using the 4G mobile standard, without any special antenna. Kuiper of Amazon started launching first sats of a 3200 sat constellation. In Europe OneWeb of Eutelsat and the IRIS-2 from EU-Commission are following this path

Same KPI and Resiliency of a dedicated network

Migration from legacy-GSM-R to technology neutral FRMCS



Migration from wired networks to wire-less solutions for Smart Wayside Object Controller SWOC

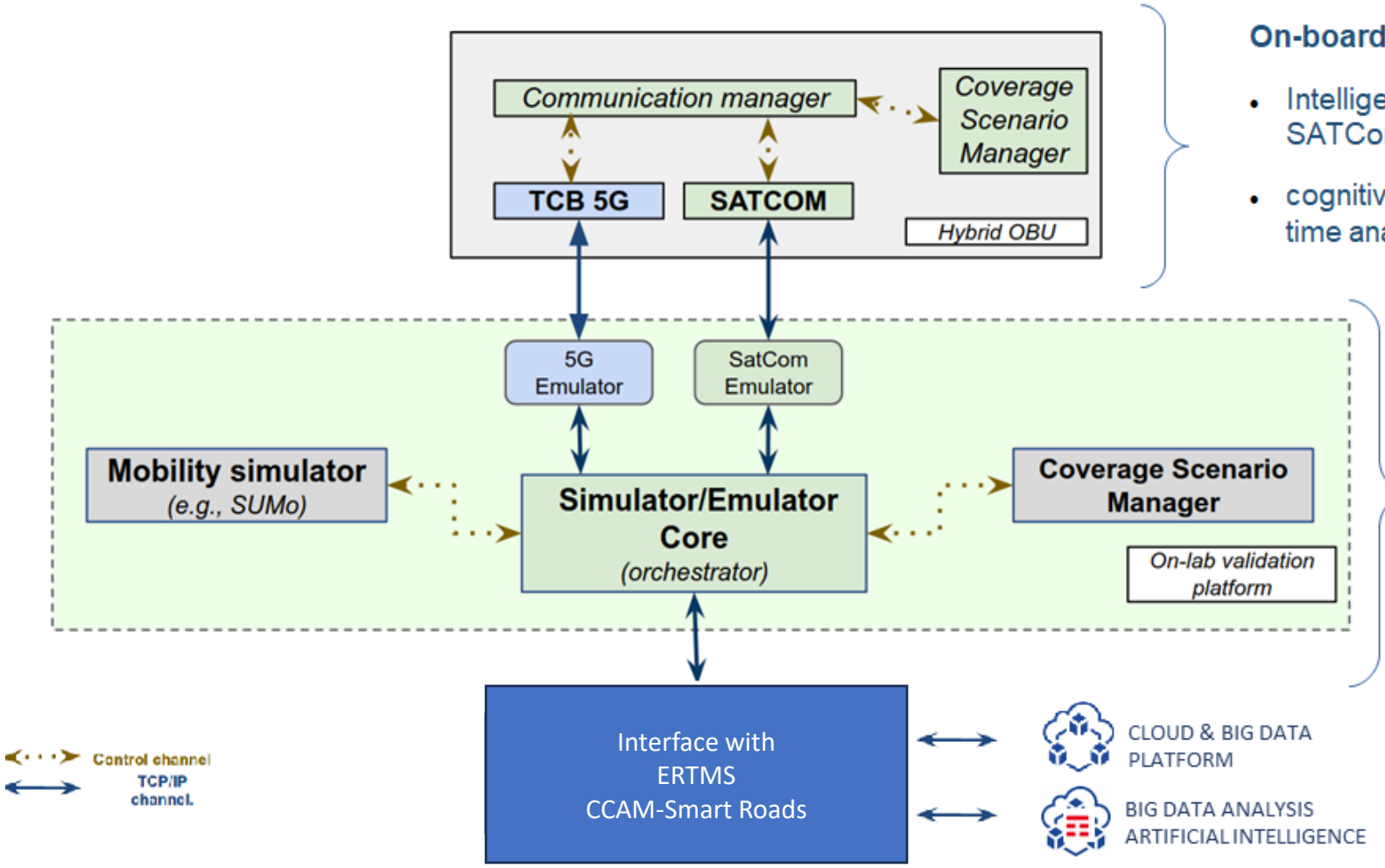


S5LECT - 5G & Satcom for Railways | Radiolabs

The emulradio4Rail project has been completed successfully - The first test in virtual mode | Radiolabs

Simulator-Emulator for Telecom Networks

Simulator-emulator tool to analyse the performance of various telecom networks in the operational scenario



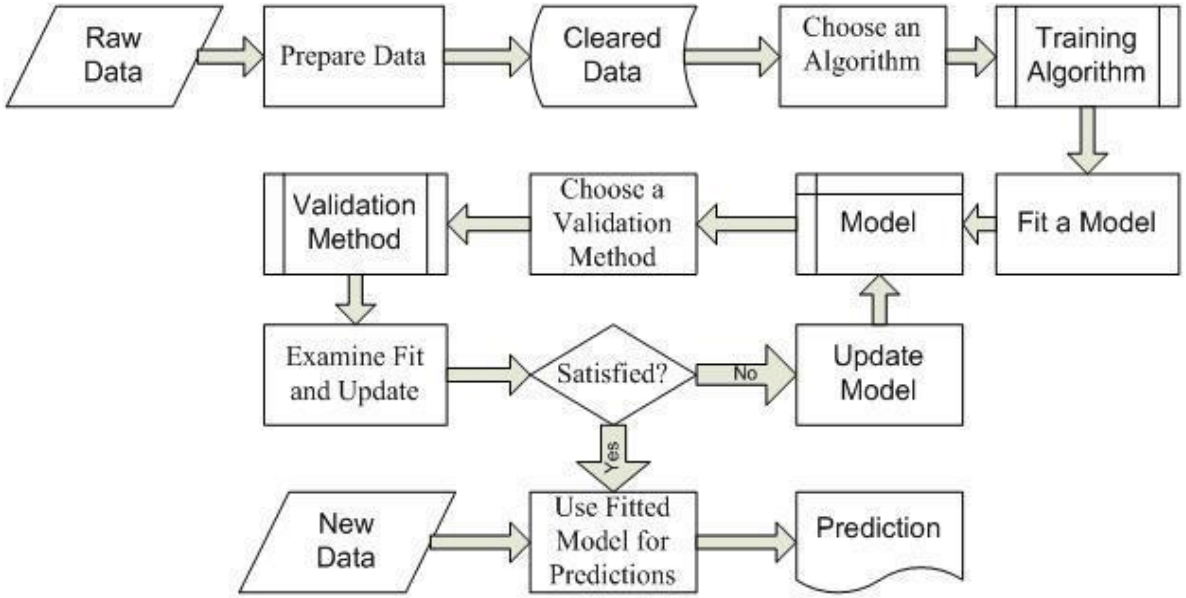
On-board telecom device (OBU):

- Intelligent handover between SATCom/terrestrial 5G technologies
- cognitive algorithms for the real-time analysis of available bearers

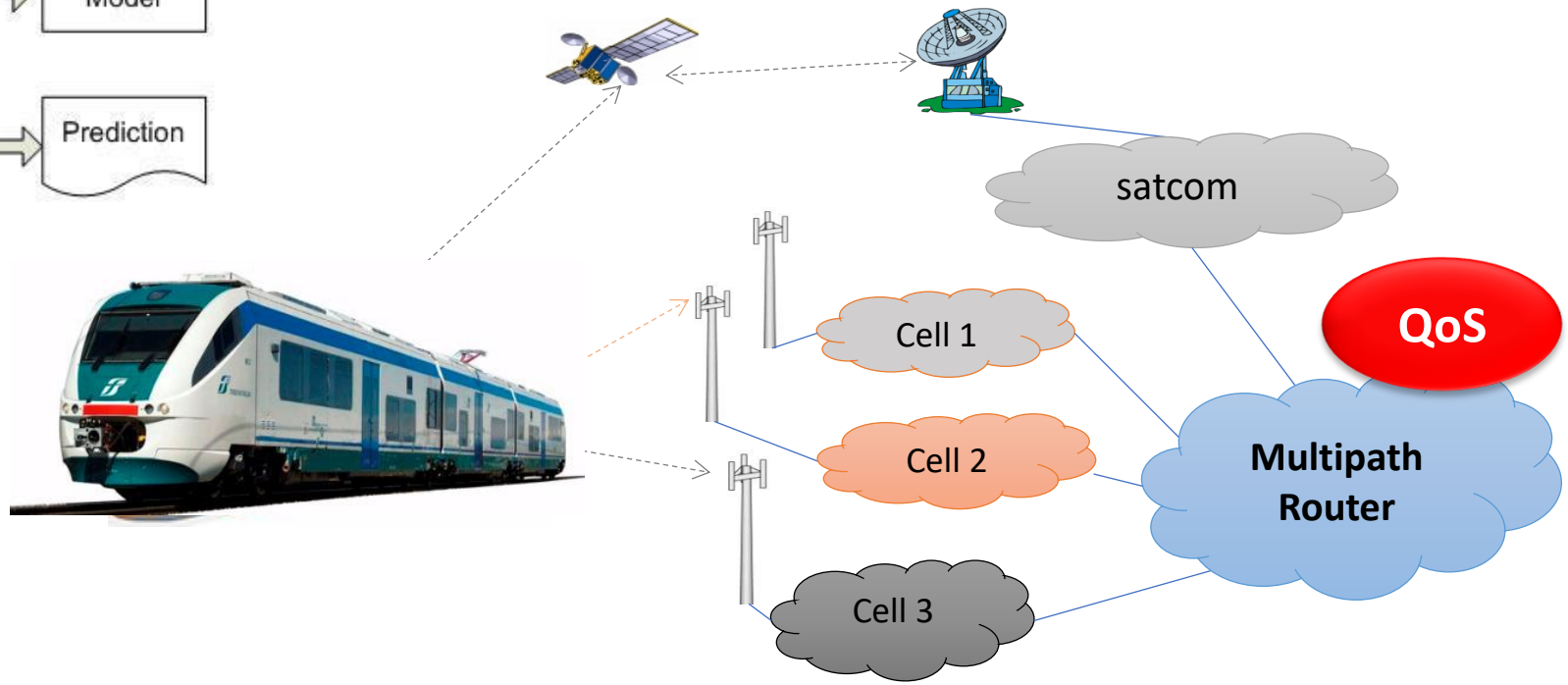
On-lab validation platform:

- Simulation/emulation of different RATs
- Simulation of vehicle dynamic and operational scenario
- Local or remote connection to the application server

Cognitive Algorithms



AI is used for processing non trusted public networks to create a multi-bearer network with at least the same QoS achievable with a dedicated network. This process is based on the collection-classification of representative data from the field and of a proper learning methodology to train the algorithms

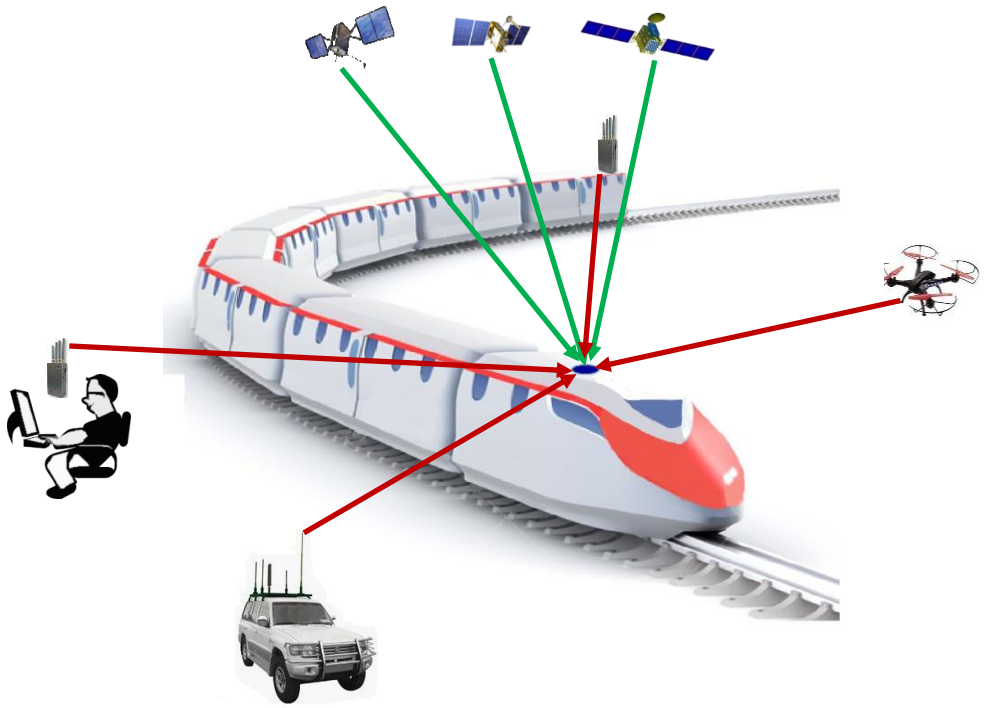


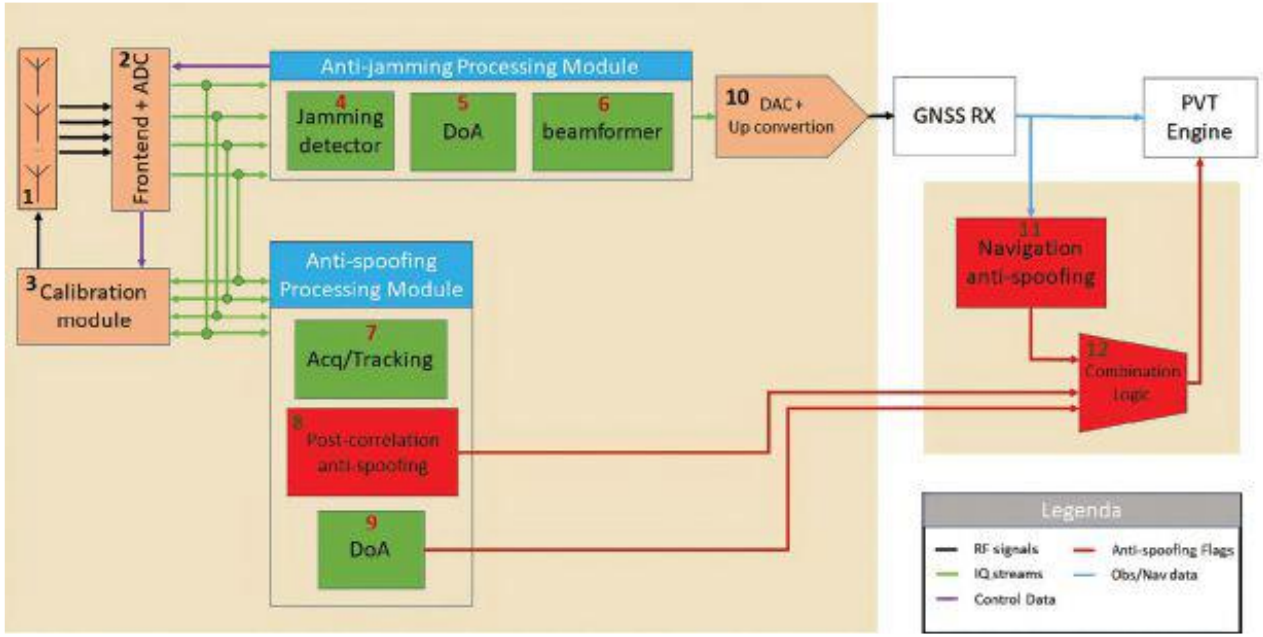
SAT4TRAIN | Radiolabs

Core Technologies

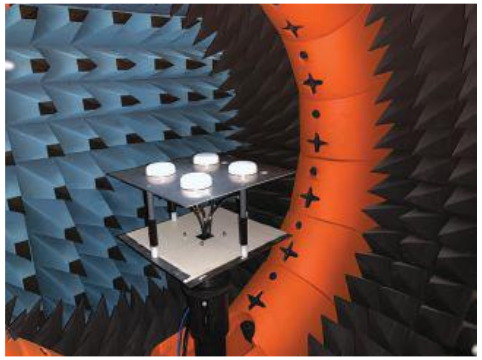
- High integrity positioning
- Satcom & public Telecom
- Cybersecurity
- Testing & Validation

GNSS Anti-jam RF-to-RF On Board Unit for ERTMS Train Control





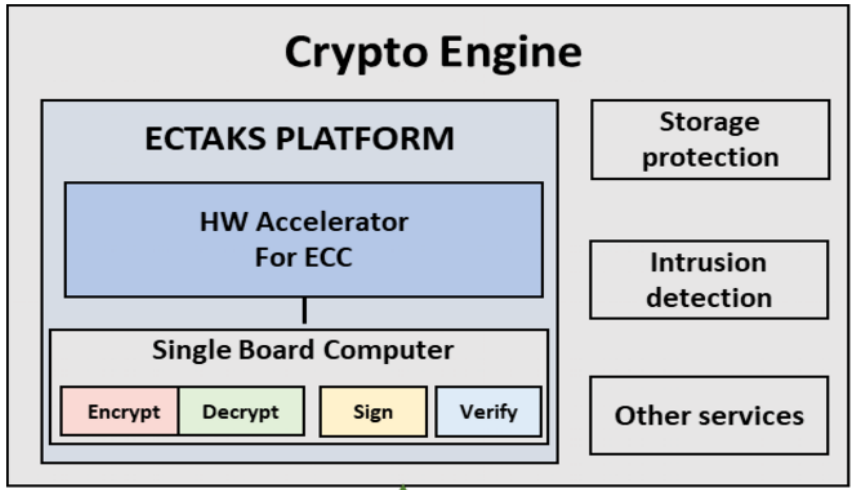
GNSS positioning has to be resilient to signal jamming and spoofing

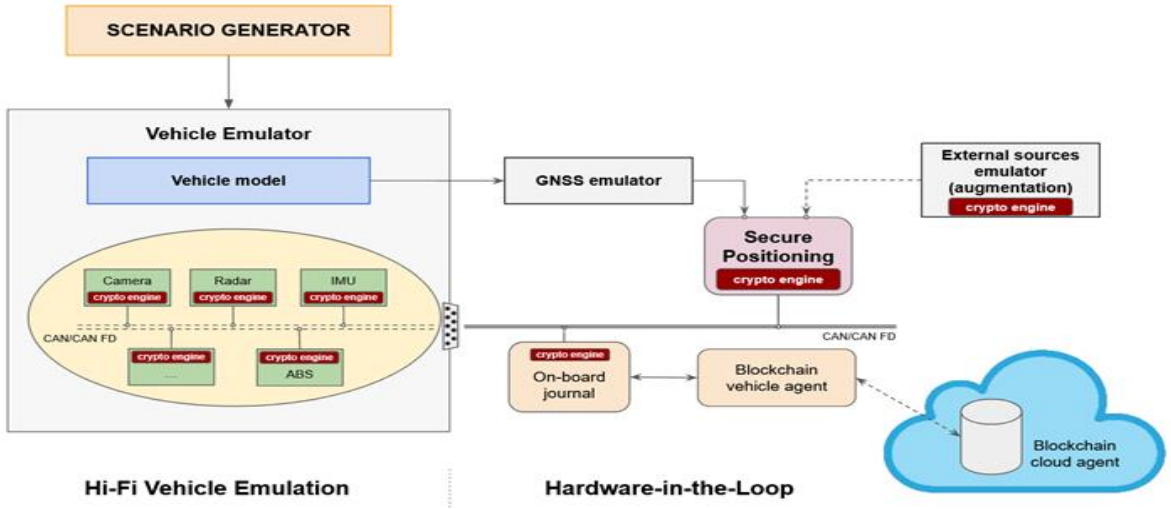


The platform consists of a 4-element phased array antenna and a 4-coherent channels front-end to detect, mitigate the jammers and cleaning GNSS signals at the input of the receiver. This platform – already verified for the ERTMS - will be engineered & tested for the Rail & Maritime applications

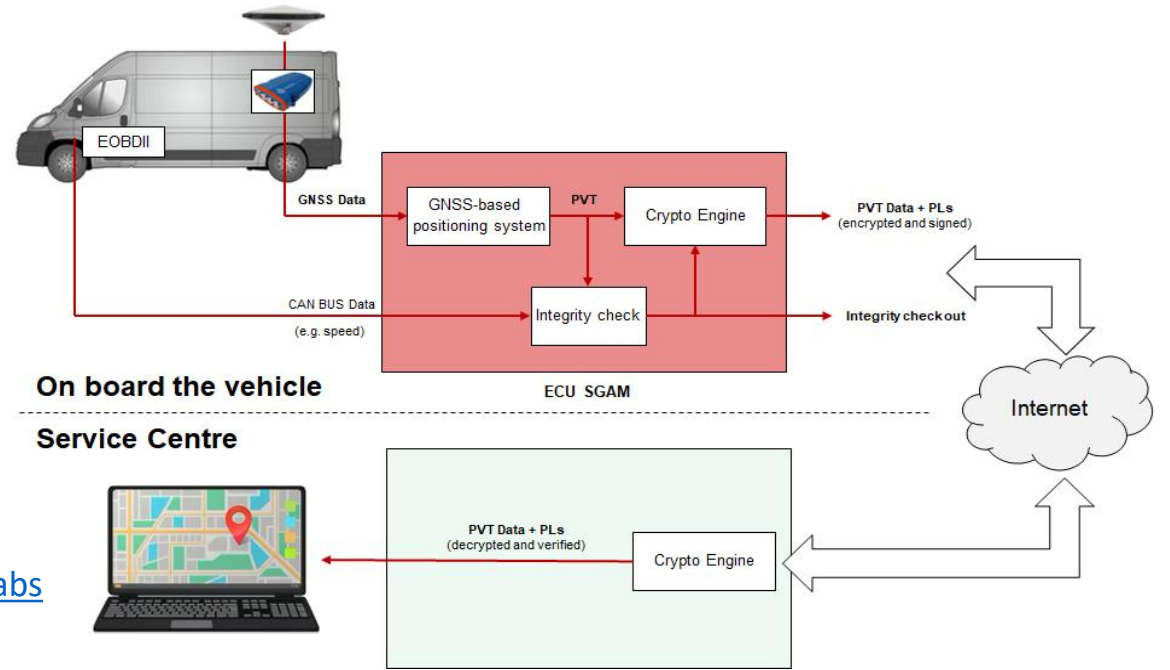
Novel Anti-Jamming Techniques for GNSS-based ERTMS Train Control - Inside GNSS - Global Navigation Satellite Systems Engineering, Policy, and Design

Cripto-engine for multi-sensor protection against cyber attacks





- **Vehicle protection architecture from Cyber attacks** through encryption and information signature algorithms implemented by the individual on-board control units (**Distributed security platform**)
- **Bblockchain-based architecture** to record sequences of exchanged information flows
- **Crypto Engine in a post-quantum cryptography perspective**.



[Cyber-secure Vehicle's positioning with post Quantum & Blockchain technology | Radiolabs]

Core Technologies

- High integrity positioning
- Satcom & public Telecom
- Cybersecurity
- Testing & Validation

The Role of Hybrid Testing for V&V and Safety Assurance

The overall development process must be verified by identifying risks and mitigation measures gaining statistical confidence in a system's ability to handle use cases, and identifying edge cases impacting the safety. Each system has to be tested in operational scenarios and an hybrid approach consisting of virtual tests in controlled environments (simulation, track, hardware-in-the-loop, software-in-the-loop, etc.) and in field tests is our approach as cost-efficient approach allowing to evaluate the behaviour of the system by injecting faults to reproducing very rare events that are difficult to identify with field tests.

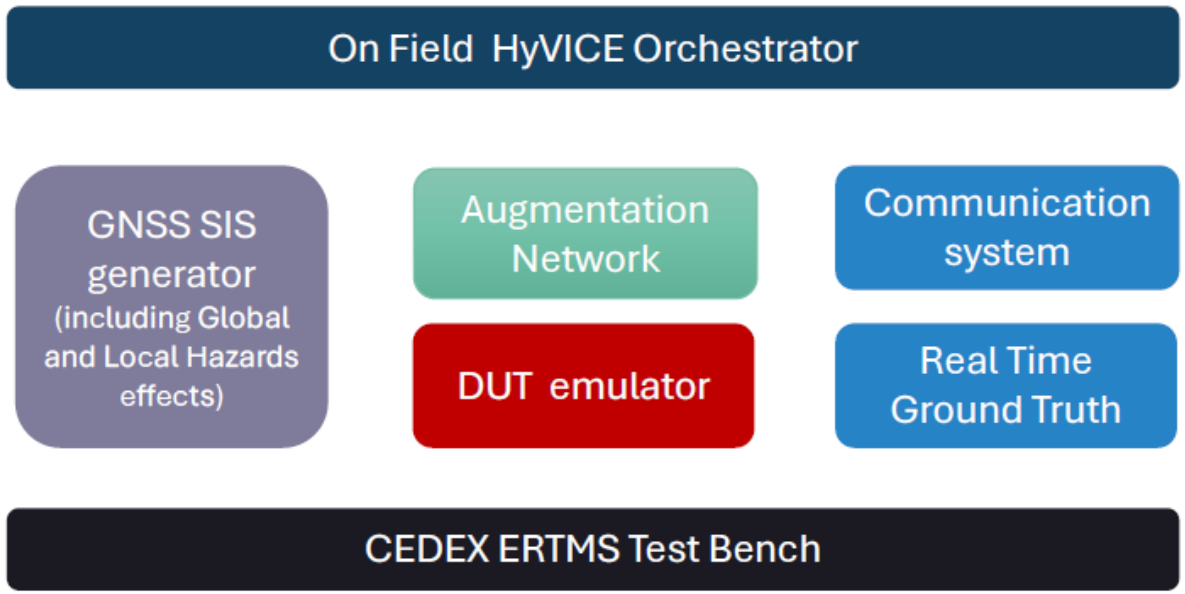
Train and car positioning based on multiple sensors from prototyping stages to production release involve several development phases. These include the ability for these technologies to perform their functions in known use cases to demonstrate a safe state when there are identified system and sensor failures, and react reasonably safely in edge cases.

We have pioneered this hybrid testing approach for the Train applications with the Gate4Rail project leading to the Vice4Rail architecture under development in the European context. For the automotive applications we are developing P-CAR a virtualised testing environment for the connected and autonomous cars aiming to become an accredited laboratory.

GATE4RAIL

Hybrid Virtualised Testing for Certification of EGNSS in Railway Train Positioning

Liaison with Europe's Rail FA2 R2DATO project




Rail Testing Site (RFI- San Donato)

Radiolabs is partner of the VICE4RAIL project to develop and deploy HyVICE - the Hybrid Virtualized Testing Certification platform to validate GNSS.-based positioning devices. The Vice4Rail system consists of a dedicated train, the railways circuit at S.Donato (5.5 Km), the laboratories of Radiolabs to emulate GNSS signals including global/local hazards, augmentation signals and of CEDEX for the ERTMS. The GNSS unit on board the train is fed by synthetic RF signals to emulating different operational scenarios. The IMU data - synchronised with GNSS – are recorded on the field to reproduce realistic behaviours. The GNSS and IMU data are then transmitted to the ERTMS laboratory to assess in one place the end2end performance of the ERTMS with GNSS-based train positioning devices under different operational scenarios.

https://www.vice4rail.eu/
https://www.linkedin.com/in/vice4rail-project/

P-CAR Laboratory

★ Baseline infrastructure for validation of a first set of Connected and Autonomous Driving (CAD) functions according to current regulations and recommendations

✔ **PHASE 1 - COMPLETED**
LABORATORY BASELINE

★ **CCAM services** assisted by smart road/smart infrastructure
★ Extension to terrestrial and non-terrestrial **communications**
★ Resilience to **cyber-attacks** of positioning services
★ **Geo-distributed** laboratory platform
★ Inclusion of **on-field testing**
★ Prepare for the **pilot exploitation**

› **PHASE 2 – ON GOING**
SMART ROAD USE CASES VALIDATION

✔ Cybersecure advanced ISA
Intersection crossing with increased awareness
Highway chauffeur- auto pilot with lane keeping, ISA, AEBS for Emergency braking and ACC for safe distance from vehicles, Platooning

★ Involvement of OEM,Tier Xs to start services, and
★ ASI, ESA, CCAM community for the qualification accreditation of P-CAR laboratory

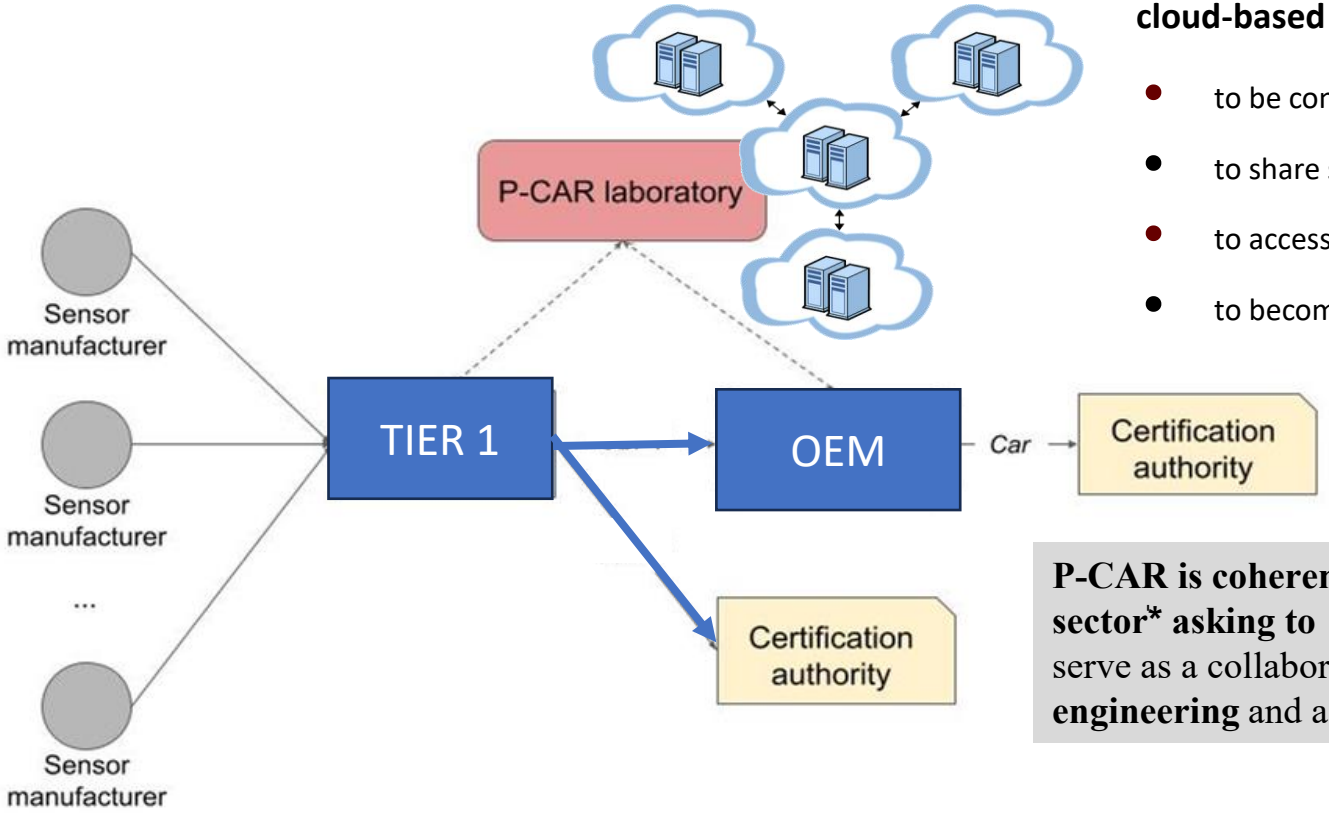
› **PHASE 3 – 2026**
PILOT EXPLOITATION + CONNECTED TRAM

Connected, autonomous driving Trams

ESA - ESA-backed autonomous driving lab set for Italy

The Role of Hybrid Testing for V&V and Safety Assurance

The performance of a **GNSS-Based Positioning Terminal** (GBPT) can be **tested, validated and verified by the manufacturer** as individual subsystems and as part of the entire vehicle architecture



cloud-based geo-distributed infrastructure

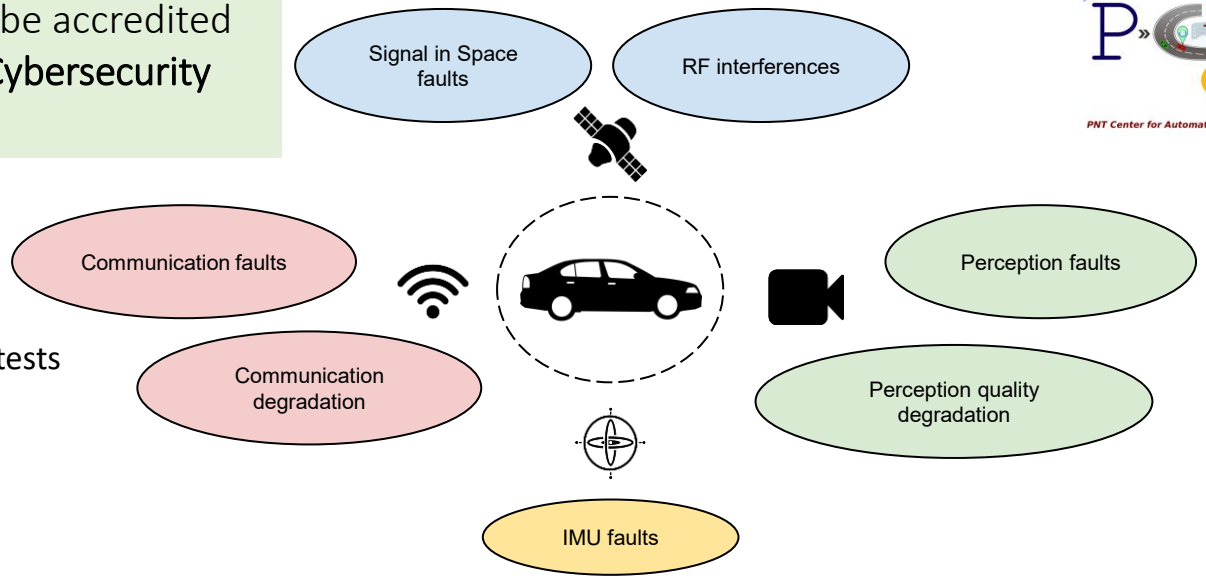
- to be connected with external laboratories and customer's facility
- to share simulation and emulation tools;
- to access computational resources for Big Data analysis.
- to become a reference & accredited laboratory

P-CAR is coherent with the EC Industrial Action Plan for the European automotive sector* asking to ***Create a large-scale distributed pilot facility in 2026/2027 that*** will serve as a collaborative environment for industry for **Software-Defined Vehicles and AI engineering** and as a testbed for innovation in application layers

*Brussels, 5.3.2025 COM(2025) 95 final

P-CAR Services

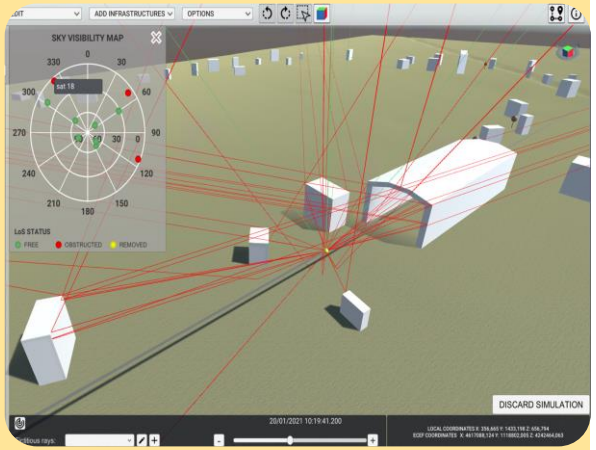
The P-CAR Laboratory is designed as an independent testing facility to be accredited at European level for testing and validating **Positioning, Telecom and Cybersecurity** technologies for the Connected and Autonomous driving applications



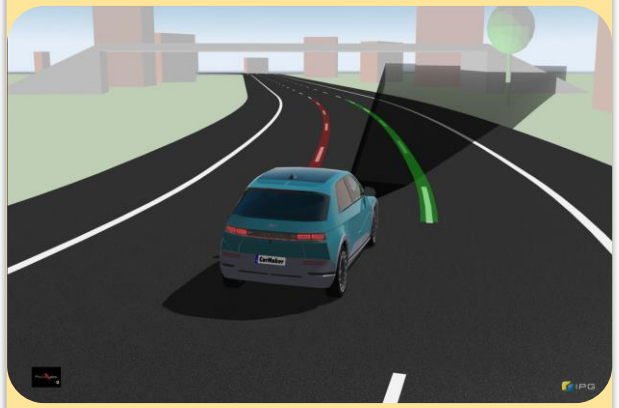
- ★ virtualised **operational environment**
- ★ Injection of faults to testing edge cases that are difficult to discover in field tests
- ★ V&V of the **user terminal**
- ★ Assessment hazard and safety risk analyses

Hardware-in-the-Loop setup

Environment-based GNSS



Environment and vehicle modelling including perception sensors



TELECOM & Cybersecurity

P-CAR Operational Modes

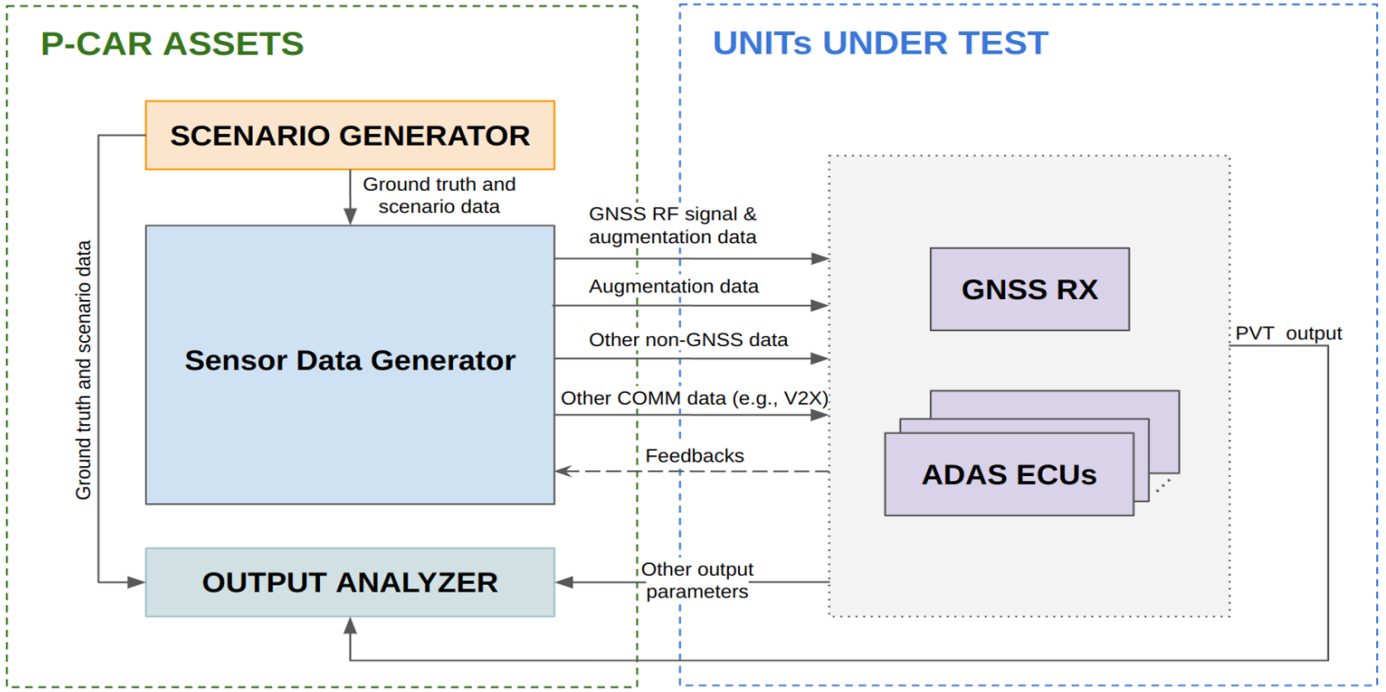
Starting from the customer's **hazard and safety risk analysis**, P-CAR will:

- **reproduce the operational environment** where the system is to be tested
- **inject faults** typical of the selected environment
- **analyse the results**
- **collect the results** into a report.

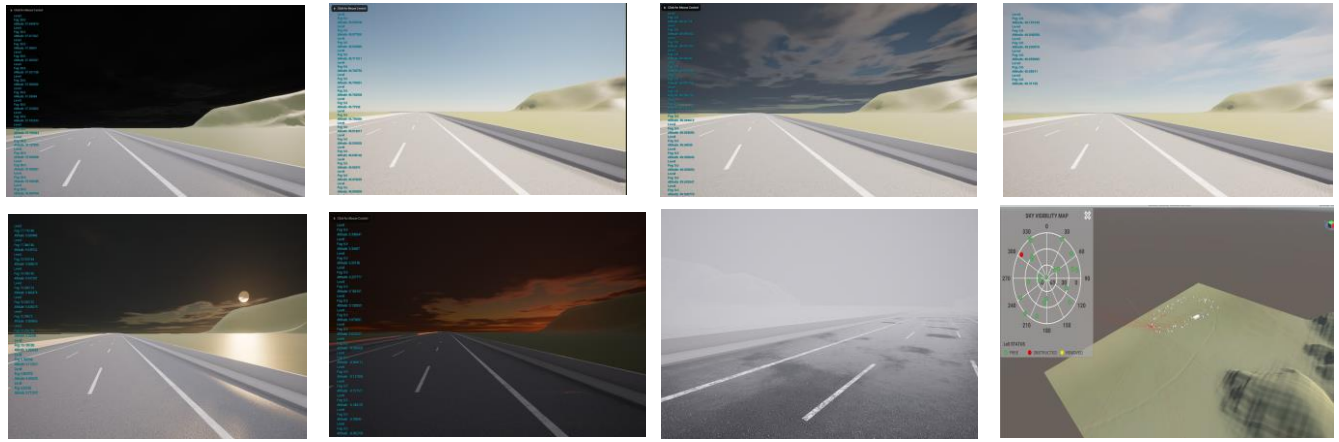
Safety requirements

- Functional Safety (*ISO 26262)*
- SOTIF - Safety of the Intended Functionality *(ISO 21448)*
- Cybersecurity *(ISO 21434)*

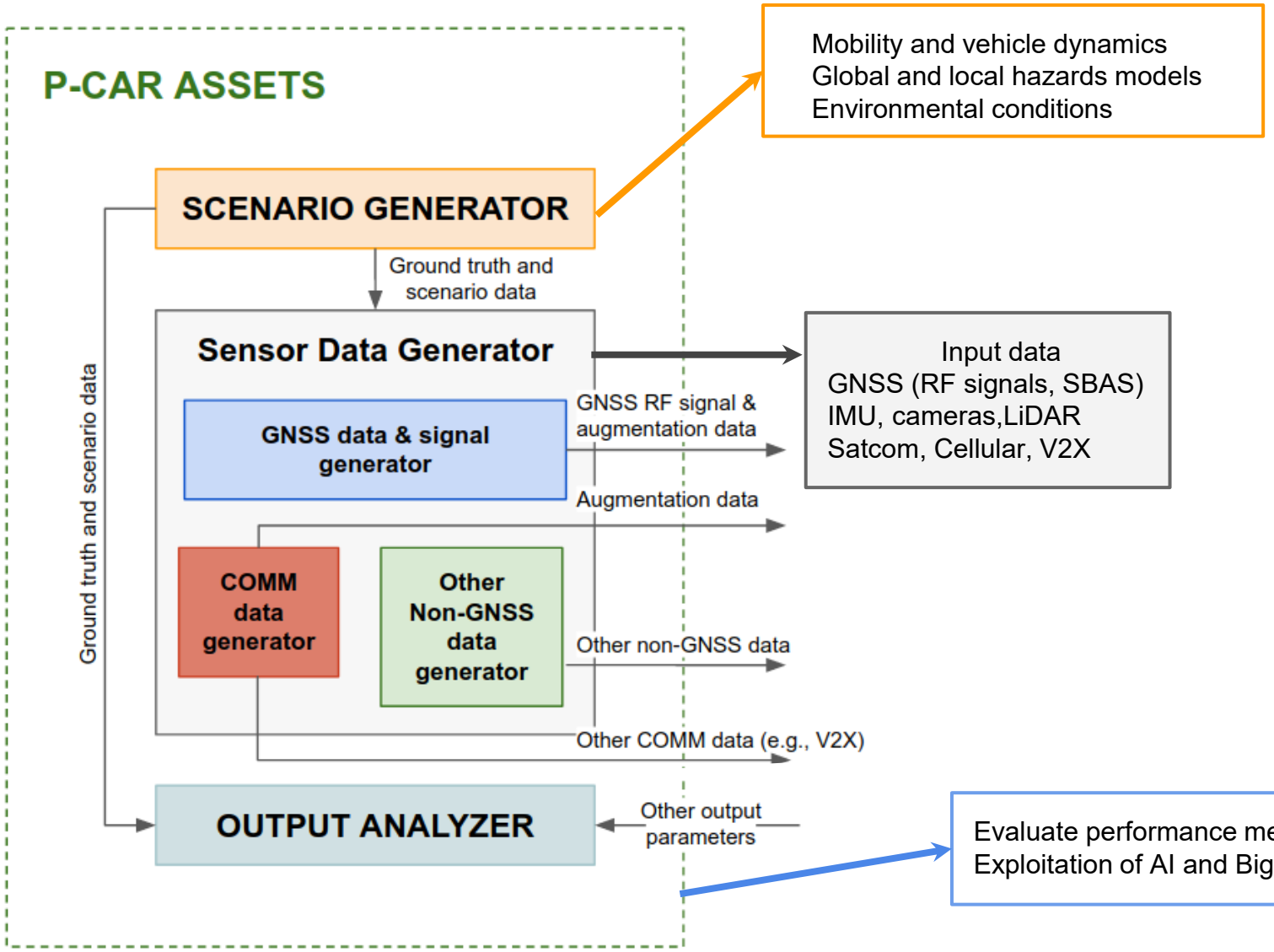
Hardware in the Loop



Exaples of testing environments



P-CAR Hardware in the Loop Laboratory

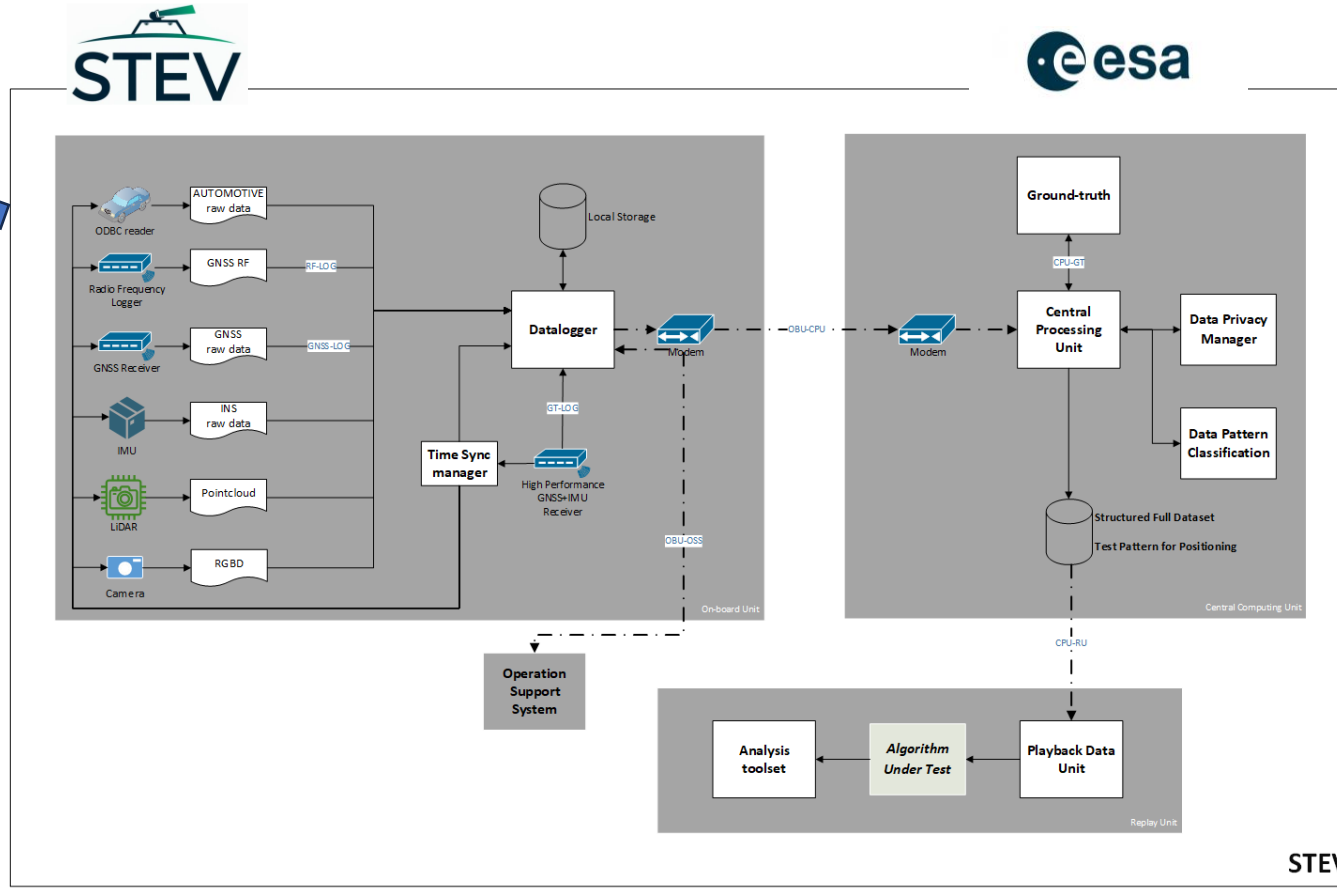


Evaluate performance metrics and the safety level on the basis of the ODD
Exploitation of AI and Big Data analysis

Sensor data acquisition and processing facility

Mobile-Lab for GNSS, Lidar, Camera, IMU data acquisition and processing. Ground truth unit for independent and trustable reference trajectory against which to evaluate the performance of each sensor in the position domain. Storage and playback processing for performance and safety assessment and for training AI algorithms. Data acquisition rate 8h @1.5Gb/s with local storage of 6TB. The standardised set-up can be installed on different vehicles and a motorcycle to get a massive data set

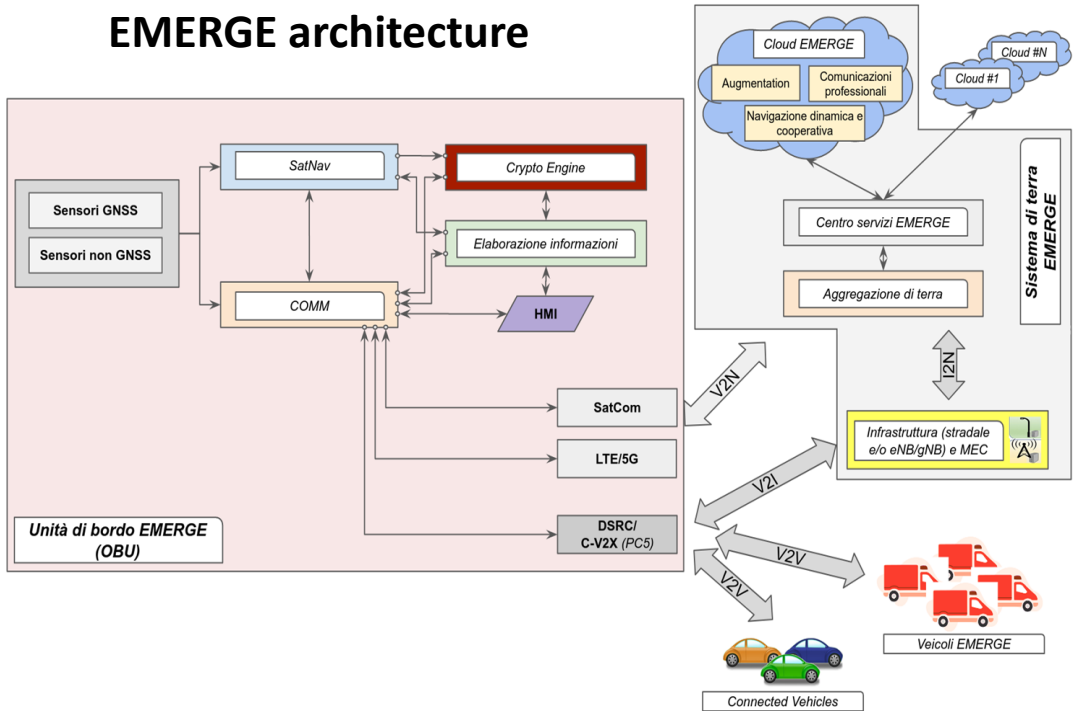
Third-party sensors and/or ad hoc systems including self-standing ADAS equipments



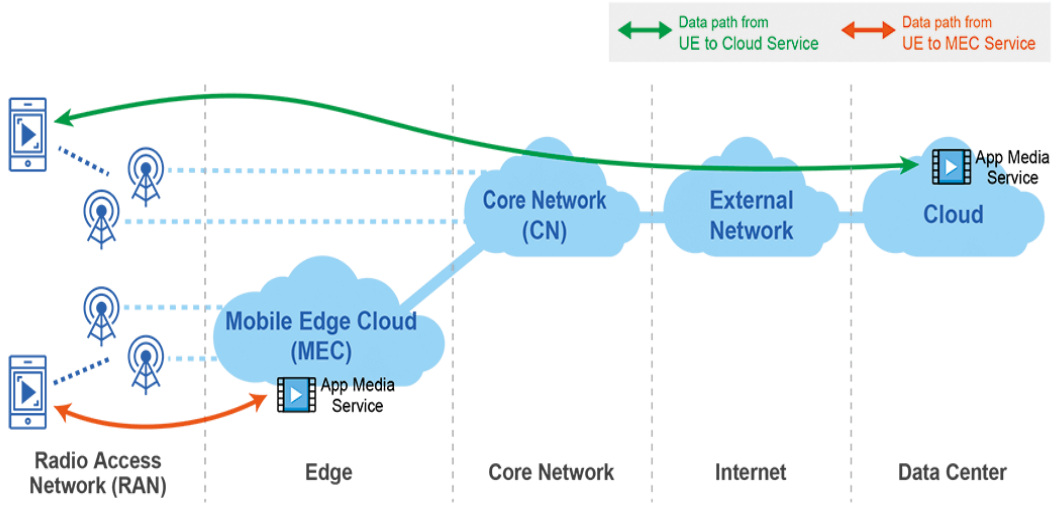
[Green light to the STEV project - Multi Sensor Positioning for Connected and Autonomous Vehicles* | Radiolabs]

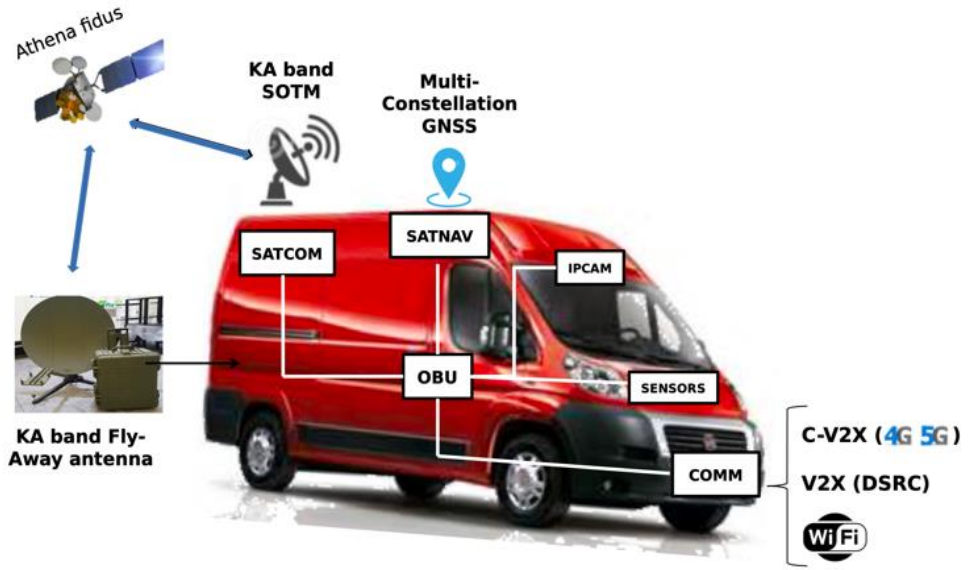
EMERGE - Testbed for Connected Vehicles Applications

EMERGE architecture



Mobile Edge Computing



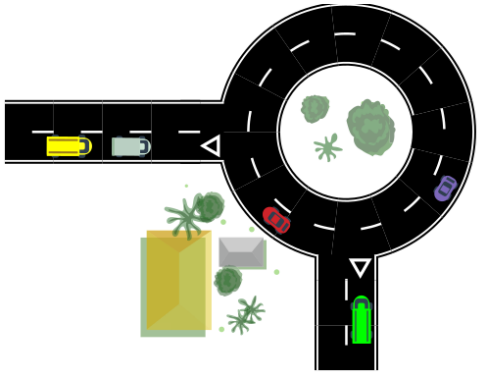


The EMERGE project - Light Commercial Vehicles with Emerging Technologies for “everyday” and “emergency aid” operations - has provided innovative services for smart mobility, through the integration of advanced technologies for high integrity positioning, multi-bearer sat & terrestrial coms and cybersecurity

[Green Light to EMERGE | Radiolabs]

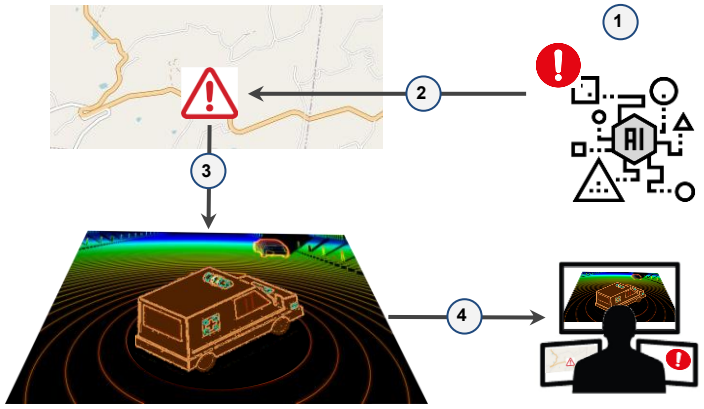
Use Cases Validated

SCENARIO	USE CASE
DAILY	**UC_D1: Virtual electronic horizon**
	UC_D2: AI techniques for efficient traffic management
EMERGENCY	**UC_E1: Detection and monitoring of critical events**
	UC_E3: Emergency corridor

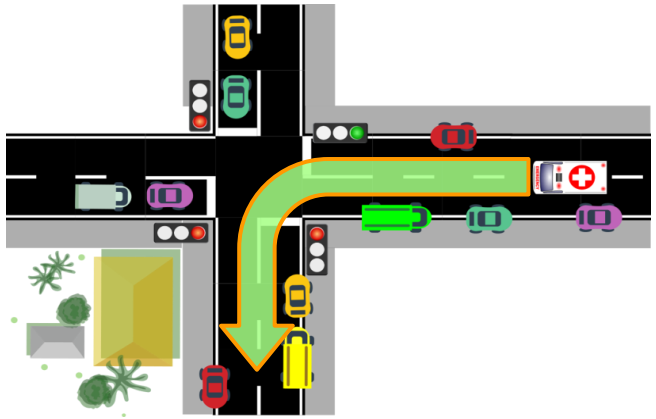


UC_D1

UC_D2



UC_E1



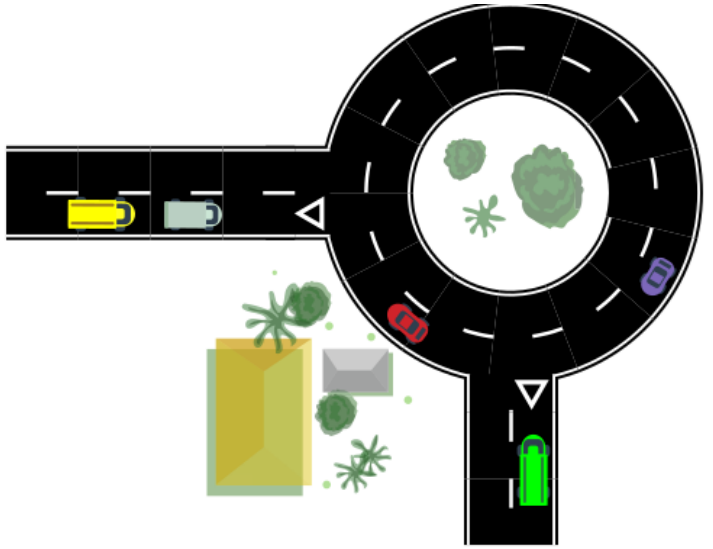
UC_E3

Daily use cases

UC_D1: Virtual electronic horizon

Objective: provide a dynamic map to the ground service center of the region of interest and enable vehicle to setup the virtual electronic horizon

Requirements: V2X connectivity and high-accuracy localization.



UC_D2: AI techniques for traffic efficiency

Objective: congestion events detection and/or prediction through **AI/estimation algorithms** to provide an alternative route to the drivers by balancing the traffic in a given area.

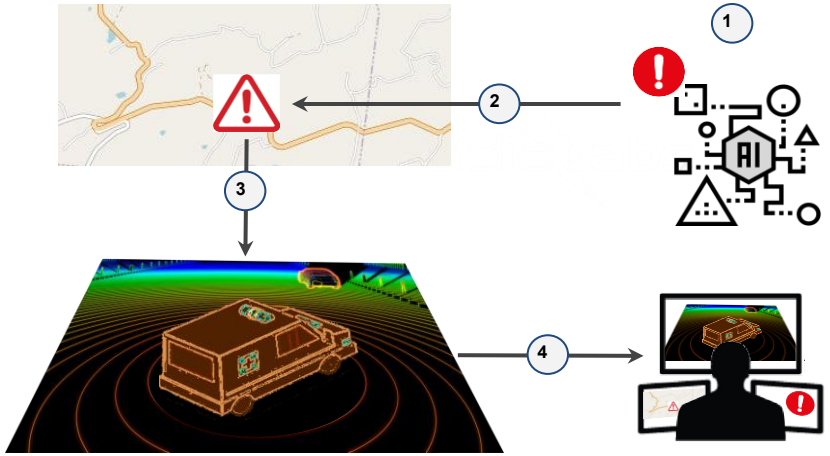
Requirements: V2X connectivity and communications towards the ground service center. The service center has to be enabled for AI/estimation algorithms computation.

Emergency use cases

UC_E1: Critical events detection and monitoring

Objective: (1) detect the critical event and (2) make the ground service center aware of the road condition.

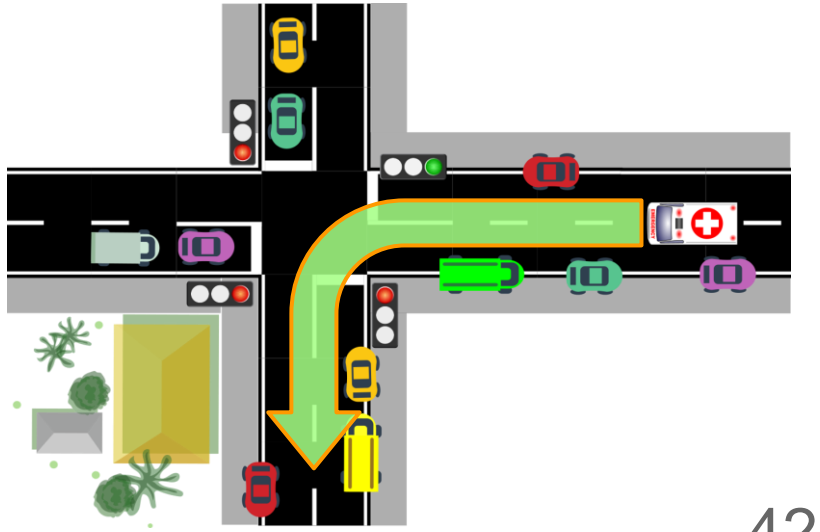
Requirements: high-reliable communication; satellite communication; high-integrity navigation system; on-board camera and other perception system. The ground service center is enabled to compute AI/estimation algorithms.



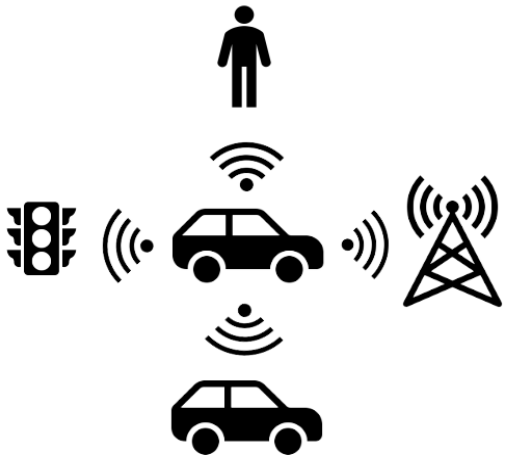
UC_E3: Special vehicle warning for a dynamic emergency corridor

Objective: the special vehicle signals its presence and provides the required information to make the other vehicles able to give-way and free an emergency corridor

Requirements: V2X communications/smart road infrastructure. High-reliable communication for the special vehicle.



Terrestrial Connectivity



- **Vehicle-to-everything (V2X)**
- **Vehicle-to-vehicle (V2V)**
- **Vehicle-to-pedestrian (V2P)**
- **Vehicle-to-infrastructure (V2I),** e.g., communication with roadside units (RSUs), traffic lights, or, in the case of a cellular network, a base station
- **Vehicle-to-network (V2N),** where the vehicle connects to an entity within the network, e.g., a back-end server or a traffic information system

V2X enabling technologies

Short/medium-range communication technology such as

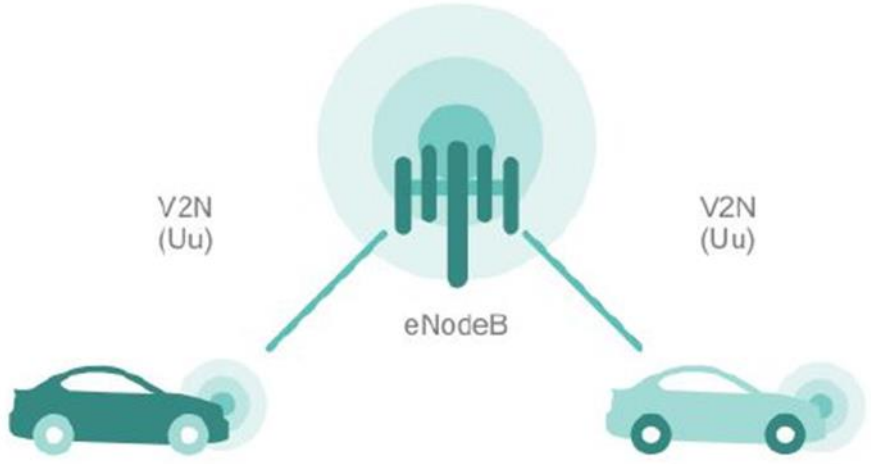
- IEEE 802.11-based V2X: it defines enhancements to basic 802.11 required to support Intelligent Transportation Systems (ITS) applications in the ITS band of 5.9 GHz (5.895-5.925 GHz);
- European ETSI ITS G5: mainly based on IEEE 802.11 for V2X, in the band of 5.875-5.925 GHz
- 700 MHz BAND INTELLIGENT TRANSPORT SYSTEMS defined in the ARIB-STD T109 Japanese standard.

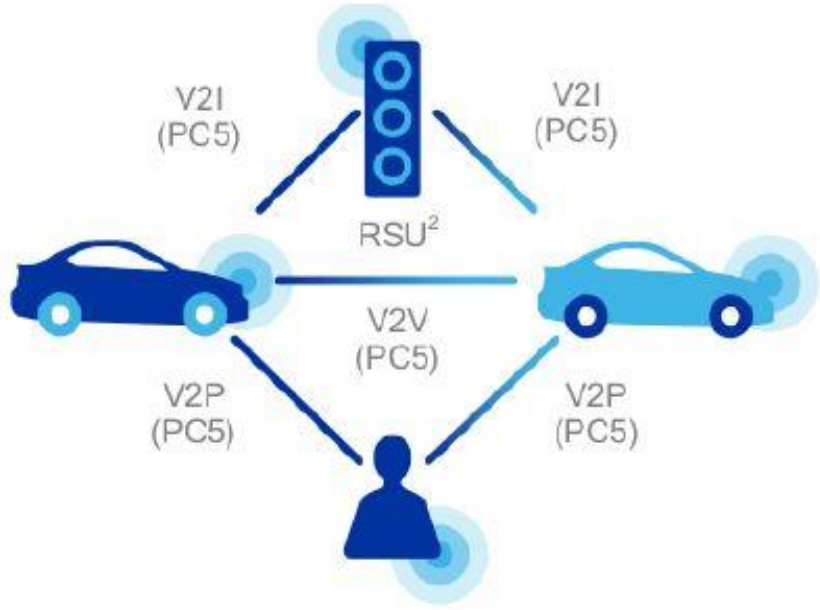
Cellular networks such as long-term evolution (LTE-V2X), 5G New Radio Cellular V2X (NR C-V2X)...

Cellular V2X modes

Since 2015, 3GPP introduced a new enabling technologies to support **C-V2X** communication, with two innovative solutions:

- Network communications with Uu Interface (RBS involved)
- Direct communications with **PC5 Interface** (Mode3 – Mode4)





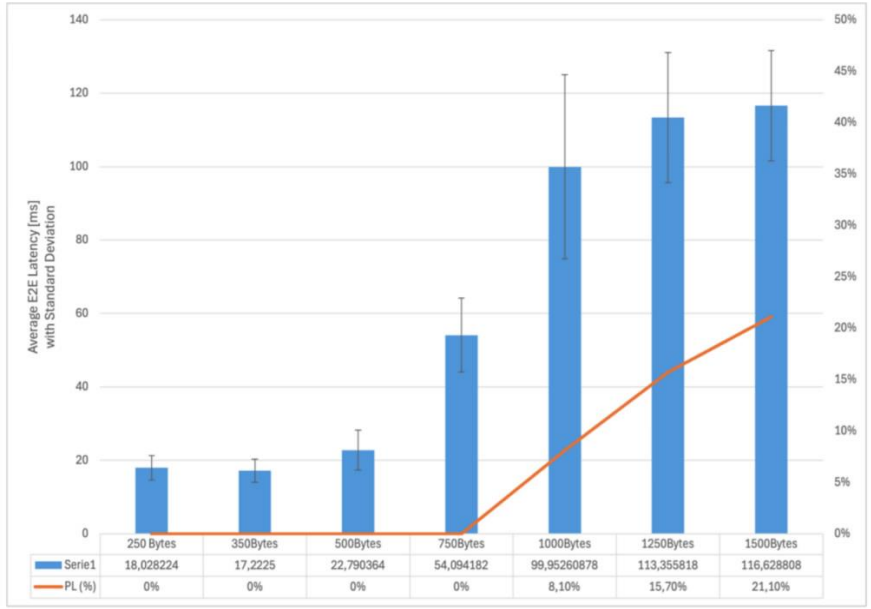
Experimental validation of V2X and C-V2X technologies

Reference standards:

C-V2X Sidelink PC5 3GPP R14

IEEE 802.11.based V2X

Cellular 5G NR 3GPP R15

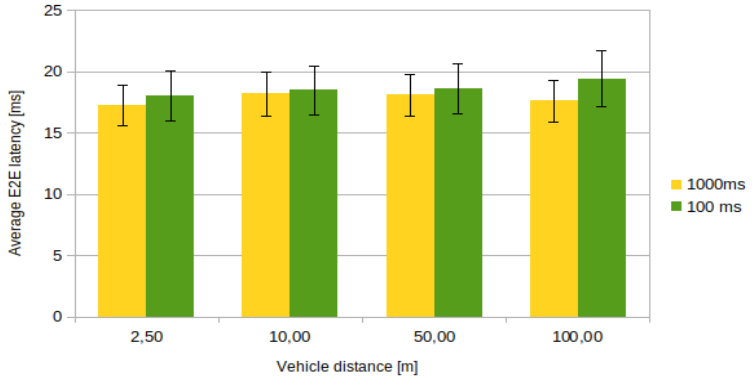


2 Cohda Wireless MK6c OBU LTE-V2X Sidelink compliant
Different environments (indoor and outdoor) as well as different on-board unit (OBU) distances and TX power have been considered.
Packet generation period: 100 ms; 1000 ms [ETSI EN 302 637-2].

Outdoor Setup - V2V link on 3GPP Release 14 C-V2X PC5 Sidelink

2 Cohda Wireless MK6c OBU LTE-V2X Sidelink compliant
Different environments (indoor and outdoor) as well as different on-board unit (OBU) distances and TX power have been considered.
Packet generation period: 100 ms; 1000 ms [ETSI EN 302 637-2].

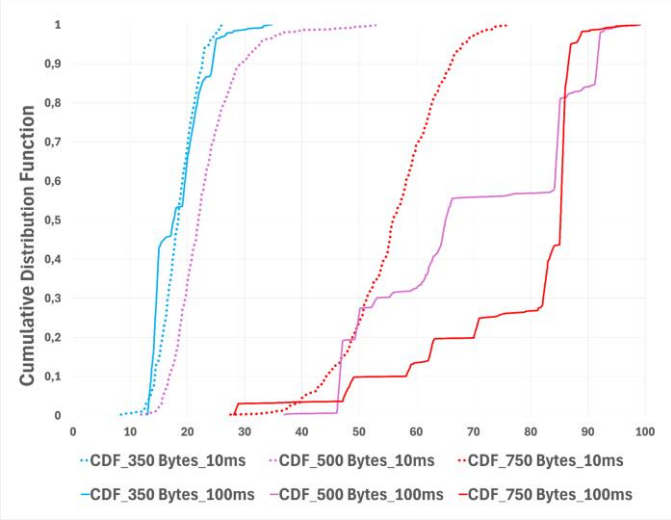
Tx Power [dBm]	Vehicle Distance [m]	Packet generation period [ms]	L_{min} [ms]	L_{max} [ms]	L_{avg} [ms]	IPG_{avg} [ms]	PDR [%]
0	2.5	1000	12.23	26.21	17.40	1000.00	100
0	2.5	100	12.30	36.40	17.75	100.00	100
23	2.5	1000	12.29	26.54	17.24	1000.00	100
23	2.5	100	11.89	38.83	18.02	100.00	100
23	10	1000	9.51	26.91	18.18	1000.03	100
23	10	100	9.99	37.91	18.47	100.00	100
23	50	1000	12.94	31.88	18.09	999.99	100
23	50	100	10.81	39.91	18.63	100.00	100
23	100	1000	12.26	27.17	17.60	1000.01	100
23	100	100	9.85	41.72	19.41	100.00	100



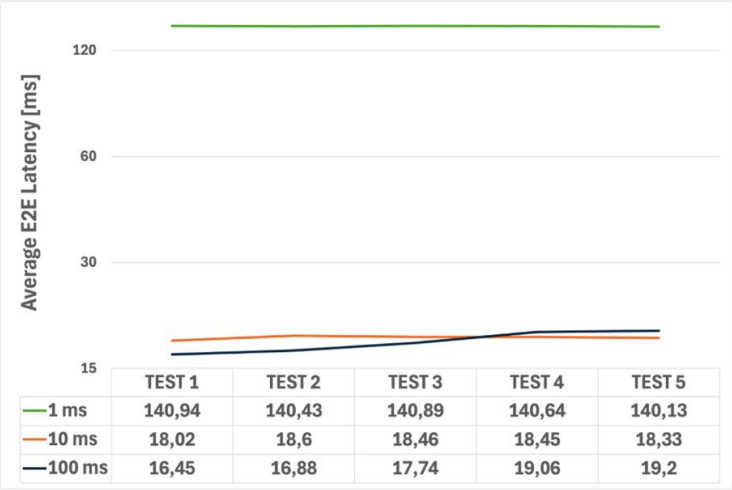
Experimental validation ofV2X and C-V2X technologies

In line with the threshold requirements defined for 3GPP R14, the max E2E for a message size of 350 bytes, never exceed 50 ms

Category	Use case example	Tx rate [Hz]	Latency [ms]
Co-operative road safety	Pre-crash sensing warning	10	50
	Vulnerable road user warning	1	100
Traffic Efficiency and Environmental friendliness	Co-operative adaptive cruise control	2	100
	Co-operative vehicle-highway automation system (Platooning)	2	100
	Traffic light optimal speed advisory	2	100
Co-operative local services	Map download and update	1	100



CDF of latency for different message sizes and transmission rates



	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5
1 ms	140,94	140,43	140,89	140,64	140,13
10 ms	18,02	18,6	18,46	18,45	18,33
100 ms	16,45	16,88	17,74	19,06	19,2

Average E2E latency for different Transmission Intervals, with Message Size = 250 bytes

Ref: G. Di Sciullo et al.,, Experimental Validation of C-V2X Mode 4 Sidelink PC5 Interface for Vehicular Communications, 2022 61st FITCE International Congress.

further “stress” tests

www.radiolabs.it