ION
INSTITUTE OF NAVIGATION

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ON GNSS AUGMENTATION SERVICES FOR THE ERTMS TRAIN CONTROL AND CONNECTED CAR APPLICATIONS: TECHNICAL SYNERGIES AND OPPORTUNITIES

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HELMET

HORIZON 2020

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EUSPA

MOTIVATION

Rail and Road transport systems are evolving toward **Autonomous Driving**.

GNSS-based high integrity and accuracy vehicle positioning is needed to comply with the required levels of safety.

Standardizable, interoperable and economically sustainable **augmentation system solutions are needed that** leverage:

- Reuse of existing and planned SBAS
- Services tailored to specific applications
- Local elements to enhance performance
- Proximity of rails and roads to share costs

ERTMS / ETCS

ERTMS / ETCS (European Rail Traffic Management System – European Train Control System) developed in Europe for high-speed lines is the de facto railway standard train control system being adopted in most new lines and major upgrades.

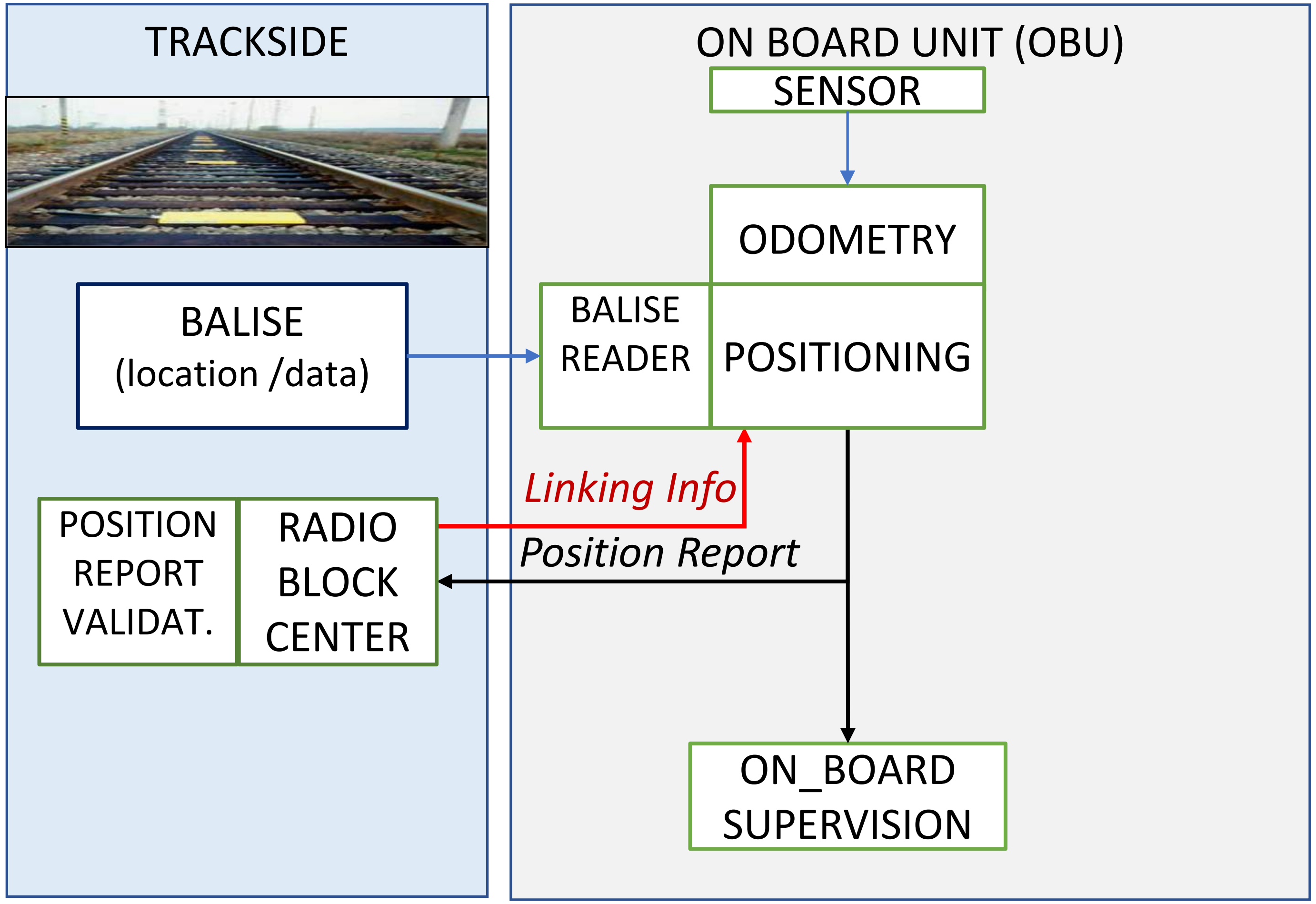
ERTMS has been designed to **replace** the different railway signalling systems in Europe with a **single system**:

- **Interoperable**
- **Standard**
- **Certifiable**

with harmonised procedures and **improved safety**

- *Railways Supported: **120,000** km*
- *In operation by **2005** in Italy @ 300 km/hr, 2 train operators, and 5 minutes headway*

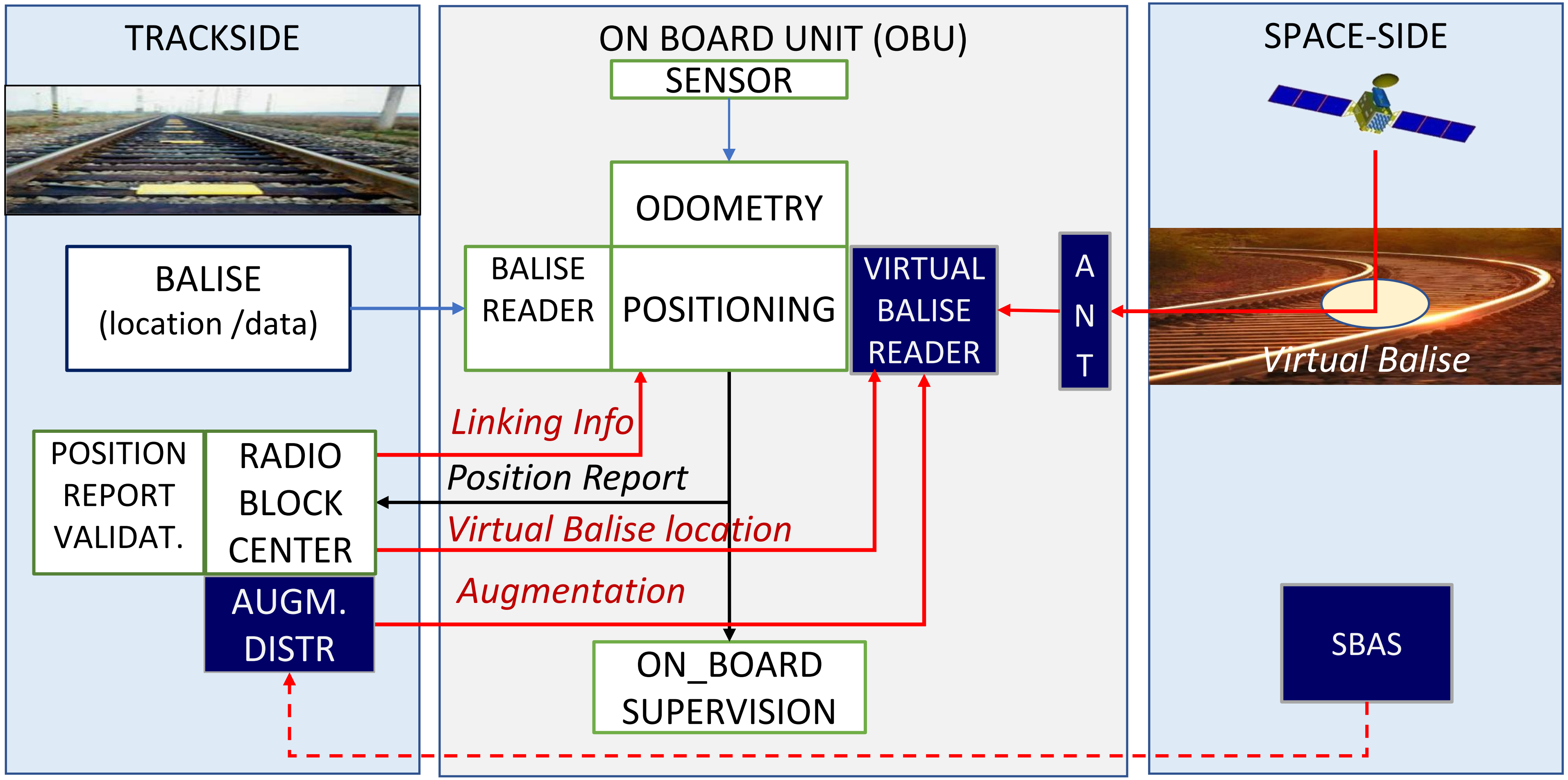
ERTMS/ETCS TRAIN LOCALIZATION



In ordinary ERTMS/ETCS, train localization is based on the combination of:

- **ABSOLUTE POSITIONING**: based on the detection of the passage over RF transponders (***Balises***) deployed along the railway
- **RELATIVE POSITIONING**: travelled distance from the last detected transponder provided by odometry

ERTMS/ETCS TRAIN LOCALIZATION



The GNSS Location Determination System generates the same signals produced by a Balise Reader detecting a physical Balise, through the same logical and physical interface, then emulating Balise reader behavior with respect to the train equipment.

In this way, the On Board ERTMS/ETCS location determination functions do not need to be changed.

WHY INTRODUCE GNSS IN ERTMS

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GNSS is one of the *Game-Changing* innovations for ERTMS

Cost reduction

Interope-rability

Additional revenues

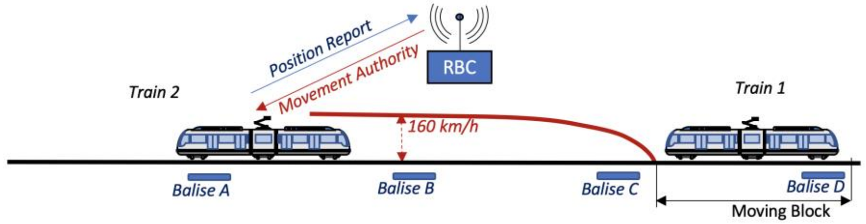
Applicability

virtual balises

Physical balises will disappear

the system is detected in the same way worldwide; certifiable for safety with a harmonised approach

higher accuracy to increase line capacity



broadening of use, including regional and local lines

MAIN CHALLENGE:

- **FULFILL THE SAFETY INTEGRITY LEVEL SIL-4 REQUIREMENTS**

A MULTIMODAL APPROACH

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Exploitation of **synergies** between rail and road applications can transform the independent operations of roads and railways into a coordinated **economically-sustainable ecosystem** – a priority of Europe.

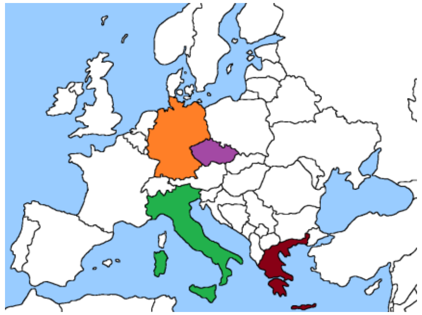
Major synergies

- Sharing telecoms and GNSS augmentation networks (rails and roads are close to each other and share the same **EM** environment and similar requirements)
- **Assimilation** of technologies and safety and certification processes
- Leveraging auto market potential to develop cost-effective multi-sensor solutions beyond the capability of the stand-alone rail marketplace

BACKGROUND: THE HELMET PROJECT

High Integrity EGNSS Layer for Multimodal Eco-friendly Transportation

Co-funded by the Horizon H2020 Programme of the European Union

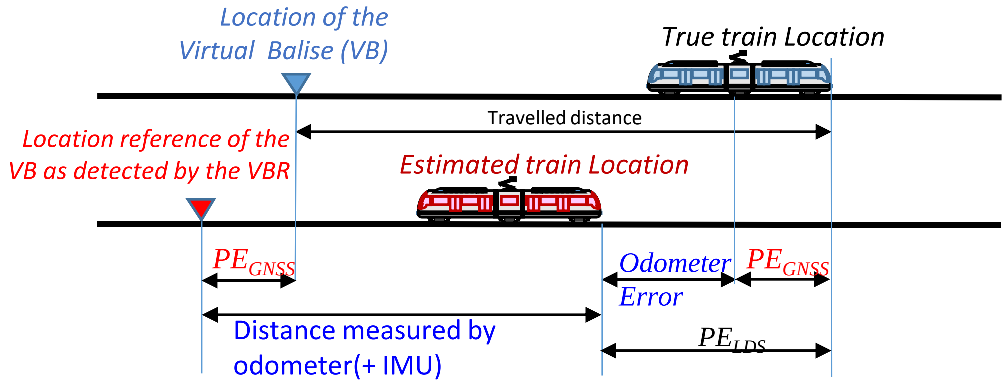


- **UNIFIED MULTI-MODAL AUGMENTATION** and **INTEGRITY MONITORING PLATFORM** supporting High Integrity, High Accuracy Positioning services for Rail, Roads and UAVs, exploiting synergies among them
- **SAFETY** framework for **ROAD** vehicles harmonized with avionics and railways best practices
- HELMET **MULTISENSOR** On Board Unit with advanced Integrity Monitoring Capabilities
- **TIGHTER** INTEGRITY **BOUNDS** incorporating (Statistical) Knowledge about LOCAL HAZARDS as part of the augmentation data
- EXPLOITATION of **EGNSS DIFFERENTIATORS** to fight back against common hazards in land-mobile scenarios
- Contribution to the standardization activities (RTCM SC 134)

RAILWAY REQUIREMENTS (ERTMS/ETCS)

- ERTMS/ETCS only uses relative positions in relation to (physical/virtual) balise groups placed in the track.
- Longitudinal position error is safety-related but not safety-critical, because margins are added by supervision functions.
- Large margins, however, may impact performance and capacity, as trains could stop or reduce speed too early.

Use case	Integrity	Accuracy (95%)		Alert Limit		Time to alert	Availability	Security
		Lateral	Long.	Lateral	Long.			
Odometry Calibration (virtual balise)	< 1e-9/h		0.70 m		1.7 m	< 1 s	High	Very High
Cold Movement Detection	< 1e-9/h		2 m		5 m	< 10 s	High	Very High
Track Identification	< 1e-9/h	0.70 m		1.7 m		10 s – 30 s		



Additional Requirements

Train orientation with respect to track

No specific performance and safety requirements have been specified for the train orientation

It can be assumed that they are similar to the track selectivity requirements.

Direction of train movement along the track

No specific performance and safety requirements have been specified for the train direction of movement,

It can be assumed that they are similar to the track selectivity requirements

Missing a balise

ERTMS/ETCS currently specifies a failure rate for a balise information point to become undetectable equal to 10^{-9} dangerous failures/hour, while the failure rate of the on-board to be able to detect the transmission of an information point equal to 10^{-7} dangerous failures/hour.

Erroneous reporting of a balise

According to Subset-036, Section 4.4.4, the balise reader should not erroneously report the detection of a balise more than 10^{-3} times/hr.

AUTOMOTIVE REQUIREMENTS

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Scenario	Integrity	Accuracy 95%			Alert Limit			Time to alert	Availability	Continuity	Security
		Lat.	Long.	Att.	Lat.	Long.					
Automated Driving on Highway	<1e-6/h	0.27 m	4.50 m	0.5°	0.67 m	11 m	1.5°	1 s	> 99.5%	High	Very High
Automated Driving on Local Roads	<1e-6/h	0.17 m	0.40 m	0.5°	0.42 m	1 m	1.5°	1 s	> 99.5%	High	Very High
Automated Driving on Narrow and Winding Roads	<1e-6/h	0.07 m	0.11 m	0.5°	0.17 m	0.30 m	1.5°	1 s	> 99.5%	High	Very High

- Longitudinal Alert Limit is mainly related to the longitudinal vehicle control
- Lateral Alert Limit is essentially determined by:
  - Vehicle side clearance, minimum passage distance, precision docking
- Cross-coupling between longitudinal and lateral accuracy increases as far as lane width and/or curvature decrease.
- Altitude accuracy requirements depend on the distance between overlapping lanes
- In addition to position and velocity, **Attitude** is required

ELECTRONIC HORIZON

Vehicles and Road users

- Position, speed
- acceleration
- direction (heading)
- Yaw rate

Static obstacles

- Position

Infrastructure

- **High Accuracy Digital map**

From other sources

- traffic
- weather information

HELMET AUGMENTATION SERVICE LEVELS

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Service Id	Description	Achievable Accuracy (95%*)	Integrity	Time To Alert	Availability	Application
SL 1	GNSS Single/Multi-Constellation Single-Frequency DGNSS /GBAS like, SBAS	2 m AT	THR_{GNSS}<1e-6/hr THR_{TOT}<1e-9/hr AL_{AT} 5 m	TTA < 10 s	High	*RAIL* Cold Movement Detection
SL 2	GNSS Multi-Constellation Single/Multi-Frequency RTK Float + GBAS (Galileo HAS****)	< 0.6 m AT/CT	THR_{GNSS}<1e-6/hr THR_{TOT}<1e-9/hr AL_{CT} 1.8 m AL_{AT} 1.7 m	TTA_{TI} 10-30 s TTA_{OC} < 1 s***	High	*RAIL* Track Identification & Odometer Calibration
SL 3	GNSS Multi-Constellation Multi-Frequency RTK Fixed/Float + NRTK (Galileo HAS****)	< 50 cm AT < 35 cm CT	THR_{GNSS}<1e-5/hr THR_{TOT}<1e-8/hr AL_{CT} 75 cm AL_{AT} 1.4 m	TTA < 1 s	High	*AUTOMOTIVE* Autonomous driving on highway
SL 4	GNSS Multi-Constellation Multi-Frequency RTK Fixed + NRTK + IMU + other sensors (odometer, camera, LIDAR)	< 25 cm AT (LR) < 20 cm CT (LR) < 10 cm AT (NCR) < 10 cm CT (NCR)**	THR_{GNSS}<1e-5/hr THR_{TOT}<1e-8/hr $AL_{CT/LR}$ 45 cm $AL_{AT/LR}$ 65 cm $AL_{CT/NCR}$ 20 cm $AL_{AT/NCR}$ 30 cm	TTA < 1 s	High	*AUTOMOTIVE* Autonomous driving on local roads (LR) & Autonomous driving on narrow and curved roads (NCR)

*: accuracy 95% for AT (along-track or longitudinal) and CT (cross-track or lateral)

**: LR stands for Local Roads scenario, NCR stands for Narrow & Curved Roads scenario

***: TI stands for Track Identification scenario, OC stands for Odometer Calibration scenario

****: Currently Galileo HAS is not available and GNSS receivers are not able to decode and apply relevant correction; it is anyway assumed that when available, such Service Level can be met through Galileo HAS if convergence time is suitable

RTCM SC-134

On June 2018 RTCM (Radio Technical Commission for Maritime Services), the international organisation working for decades into the field of High Accuracy GNSS System standardization, founded a new Committee SC-134 entitled "Integrity for High Accuracy GNSS-Based Applications".

The main scope of this Committee is to study and develop standards for emerging applications needing both High Integrity and High Accuracy navigation.

Four Working Groups have been created for this scope:

- WG 1: Automotive
- WG 2: Rail
- WG 3: Maritime and Other Applications
- WG 4: Harmonization of Requirements and Metrics.

In this work, RTCM includes the relevant heritage coming from RTCM SC-104 standards on Differential GNSS that define the standards and protocols currently used for Real-Time Kinematic (RTK), Network RTK, and Precise Point Positioning (PPP) system developments.

The intention of the Committee is, starting from a completed critical detailed review of relevant Requirements, Standards and Safety Analysis for each application domain, to proceed with the definition of relevant Augmentation Messages for High Accuracy and High Integrity System implementations.

Safety concepts and metrics (e.g. tolerable hazard rate [THR] vs. aviation integrity risk [Pr(MI)]) are integrated into the WGs work for meeting Transport Requirements.

In order to guarantee backward compatibility with historical developments in the High Accuracy application sector, SC-134 Augmentation Messages will be integrated within the long-standing and consolidated RTCM SC-104 message format structure and protocol – i.e., Networked Transport of RTCM via Internet Protocol (NTRIP).

HELMET

MAJOR HAZARD SOURCES & MITIGATIONS

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Sky View & Visible Horizon

LOCAL HAZARD MITIGATIONS

HELMET LOCAL HAZARD SOURCES MAPS

- Camera Visible Horizon
- Signal Domain
- Correlation Domain
- Measurement Domain
- Position Domain (ARAIM)
- **SENSOR FUSION**
- **Hybridization with 5G**

Rail and Road On Board GNSS receivers are prone to:

- **GLOBAL HAZARDS:** *error sources with sufficiently high spatial correlation that Augmentation Techniques are effective*
  - *Ephemeris and satellite clock errors, Ionospheric and tropospheric delays, Inter-frequency biases, wind-up effects, solid tides, …*
- **LOCAL HAZARDS:** *error sources with very low spatial correlation like shadowing, multipath, and RF interference*
  - *For these, HELMET provides a statistical, space varying, description of their behavior*

MULTI-MODAL MULTI-SERVICE ARCHITECTURE

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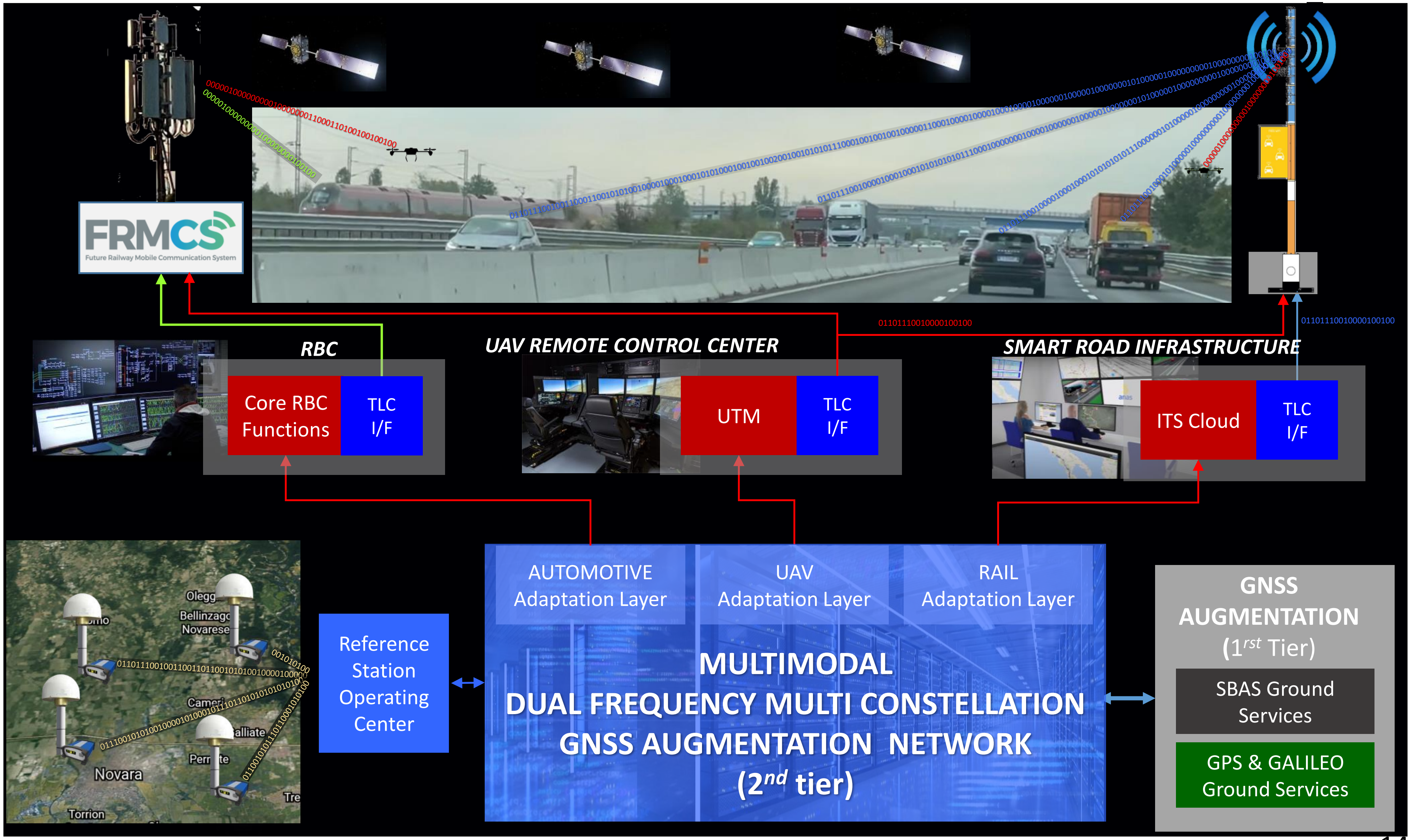
Features

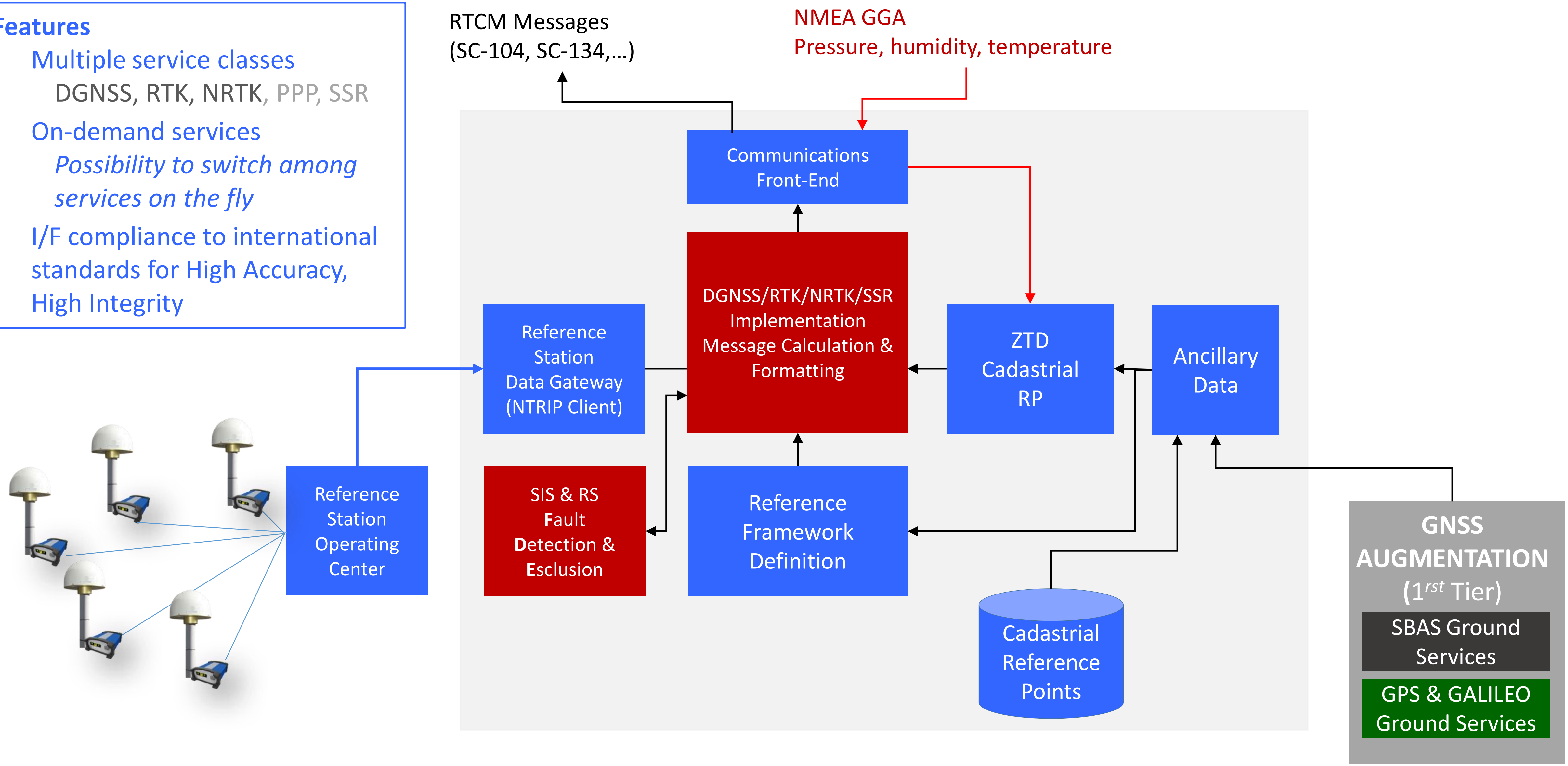
- Augmentation messages (e.g. Reference stations raw data for RTK, precise orbit and SVs clock corrections)
- Integrity parameters coordinated with specific user applications
- Use of EGNOS, Minimum and Extended Integrity Messages (e.g. Satellite, Constellation and Reference Station Health Status flags, following 2-Tiers approach and RTCM SC-134 draft proposals) to provide integrity functions.
- Certifiability with respect to CENELEC norms.
- Use of a private, secure, and high QoS communication network to connect the local network.
- Processing of advanced corrections algorithms and standard corrections data formats (RTCM SC-134 Extended messages and overbounding parameters)



AIMN ARCHITECTURE

Features

- Multiple service classes
  DGNSS, RTK, NRTK, PPP, SSR
- On-demand services
  Possibility to switch among services on the fly
- I/F compliance to international standards for High Accuracy, High Integrity



RAIL MULTI-SENSOR PLATFORM

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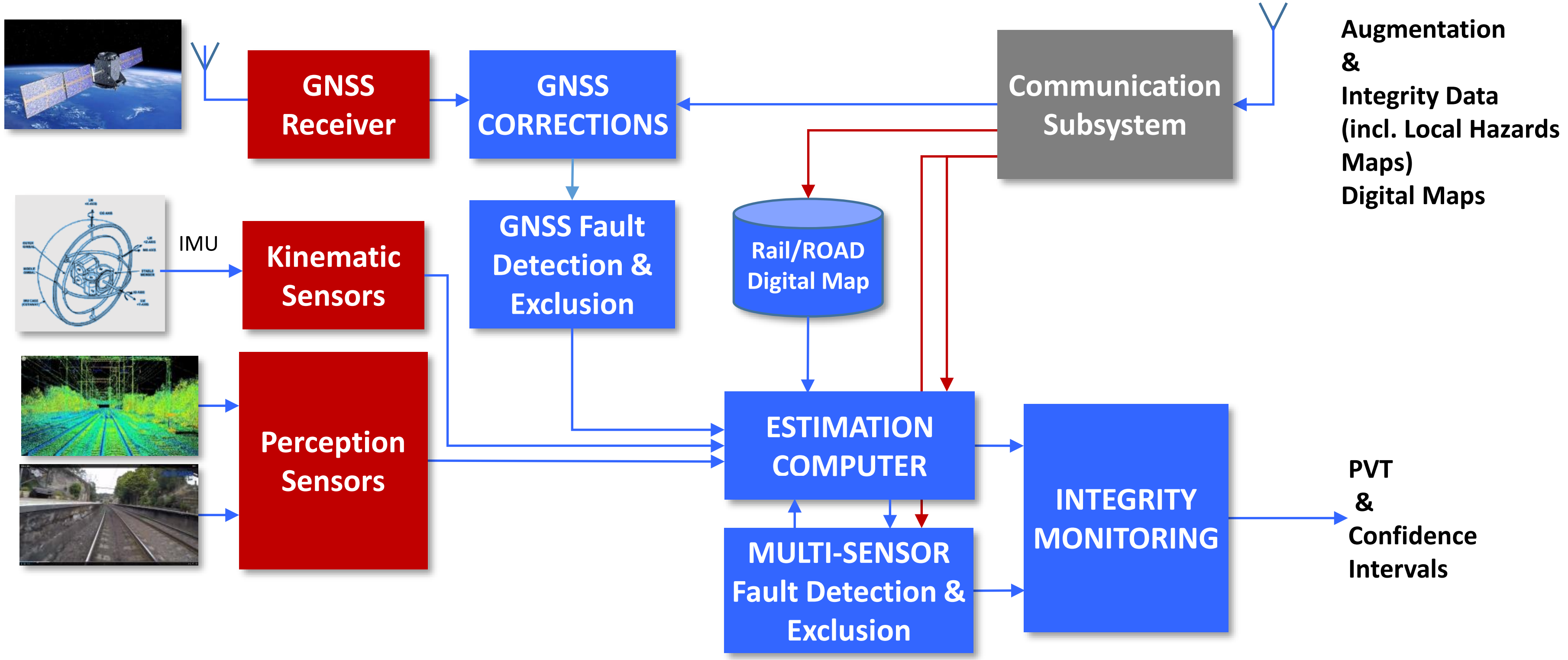

- The HELMET On Board Unit reference architecture has been designed to meet today's requirements (e.g., Virtual Balise support) but with enough growth capability to support future needs (e.g., Enhanced Odometry as well as full integration of hybrid navigation solutions into fully Automated Vehicle Control).
- GNSS + IMU + Mechanical Odometer + Video + Lidar + … are processed by the navigation subsystem along with the data provided by the augmentation network.
- The integrity monitoring procedure excludes faulty measurements, estimates Protection Levels, and ensures integrity for each application.
- A communication subsystem (e.g. FRMCS) ensures secure interaction between the ground segment and the on-board unit.

EXPERIMENTAL RESULTS

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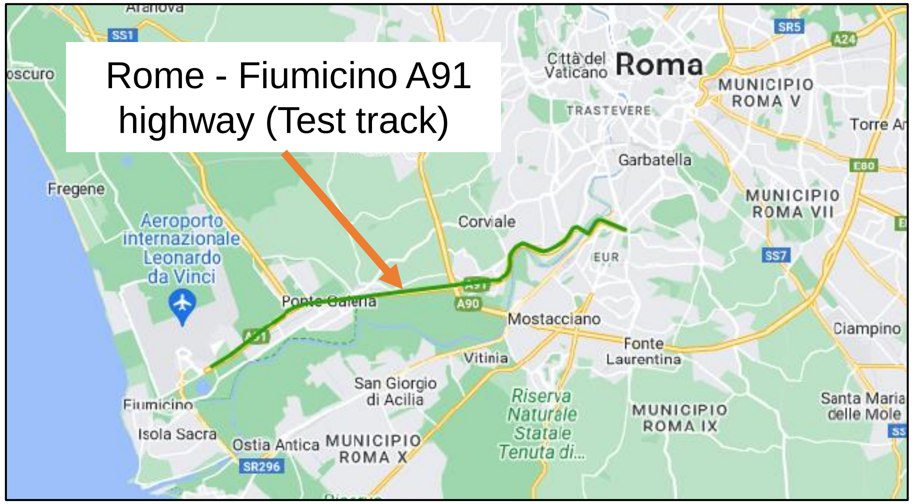
To emulate realistic GNSS-based train positioning that exploits a track constraint by using a road vehicle, a track digital map has been built by integrating a digital map with lane centerlines obtained by RTK post processing of GNSS data acquired by a vehicle equipped with lane keeping and imaging recording facilities.

Track constraint based on RTK post-processing of recorded GNSS data



Rome - Fiumicino A91 highway (Test track)

Scheduling of activities

- First acquisition campaign for **trackDB creation** (April 7)
- Second acquisition campaign for **post processing analysis** on the PVT calculated by the OBU (April 12)
- Field test campaign for **real-time processing** of GNSS data + Sogei augmentation (April 12)

During the tests, environmental data from on-board cameras were collected for in-depth post processing analysis.

EXPERIMENTAL SETUP

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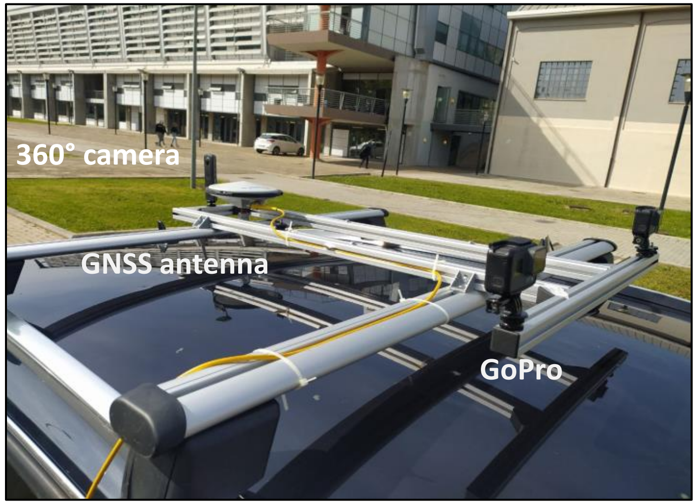
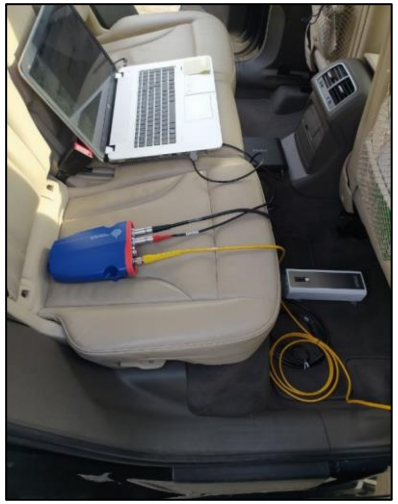
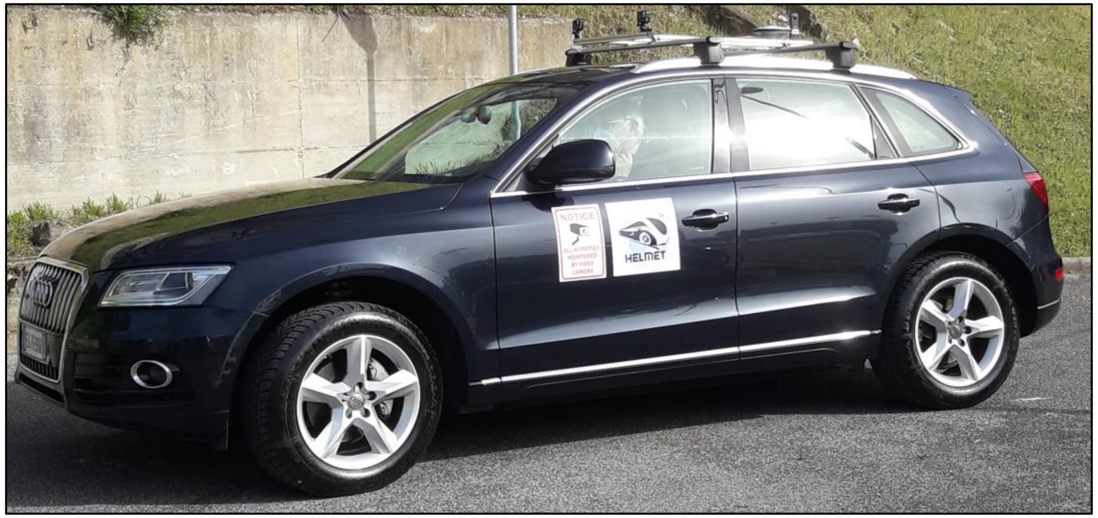
Rail MOBU High Fidelity Emulator





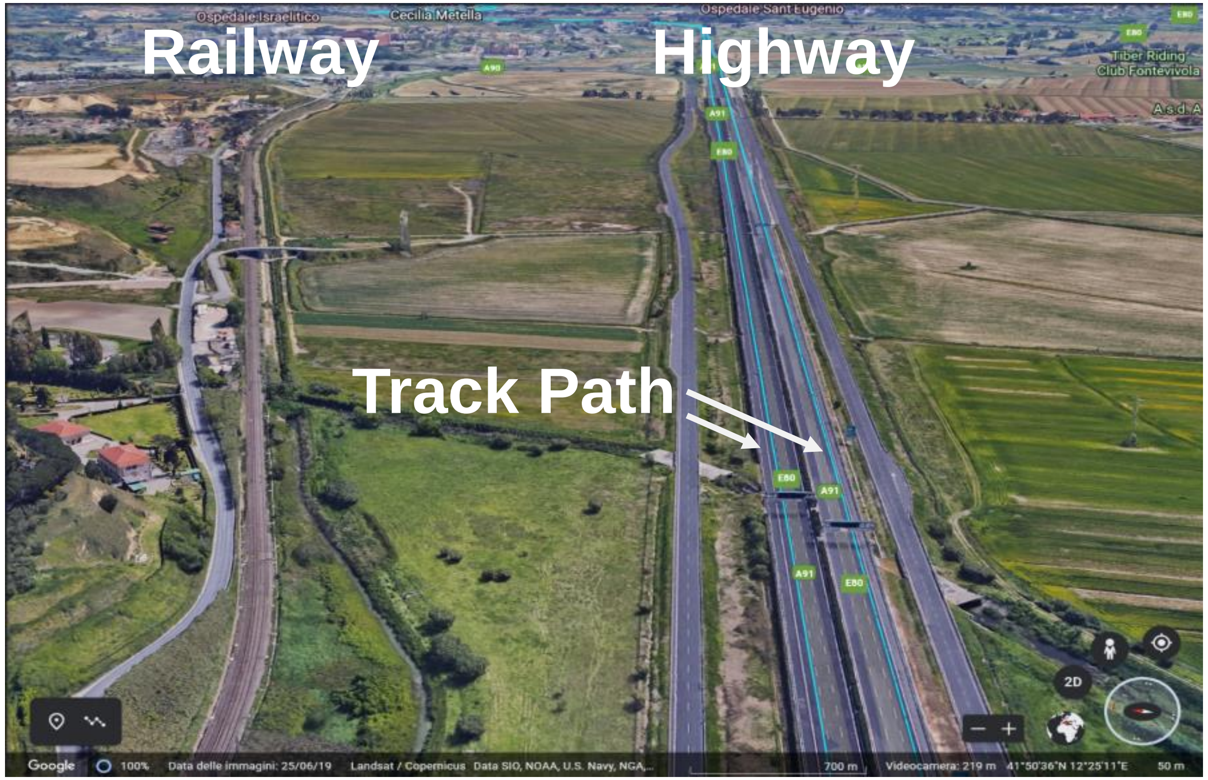


TEST EQUIPMENT

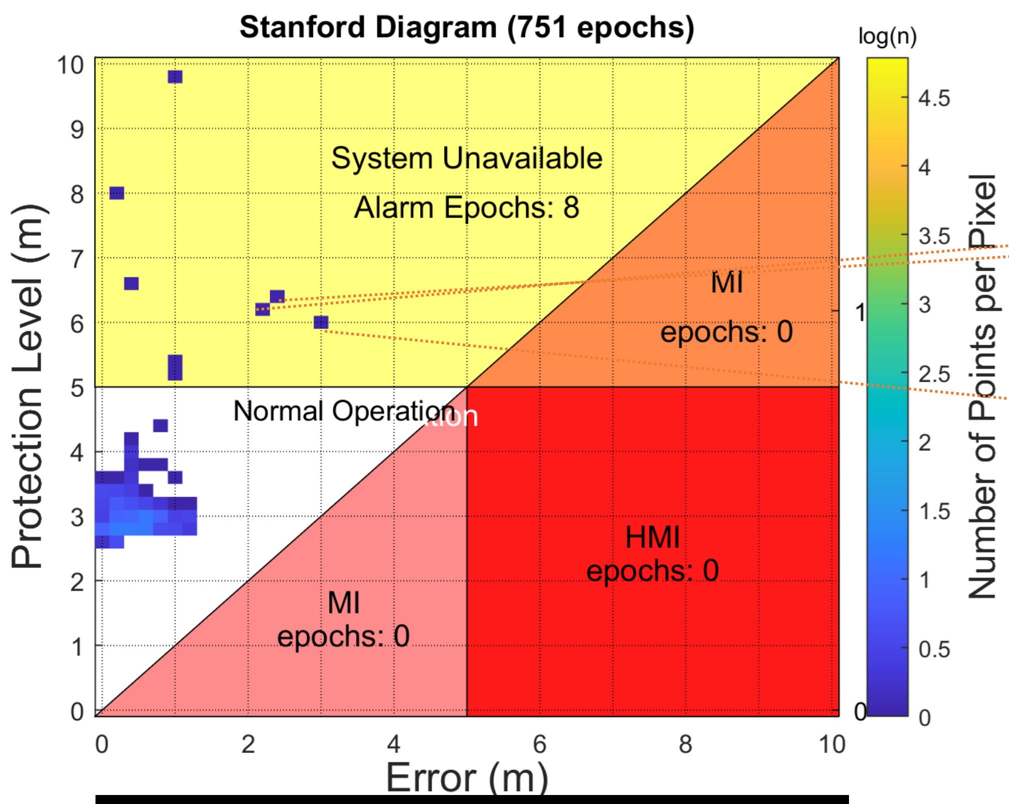
Mobile Unit: GNSS receiver (Multi-Frequency GPS + GALILEO) + cameras (GoPro + 360°)

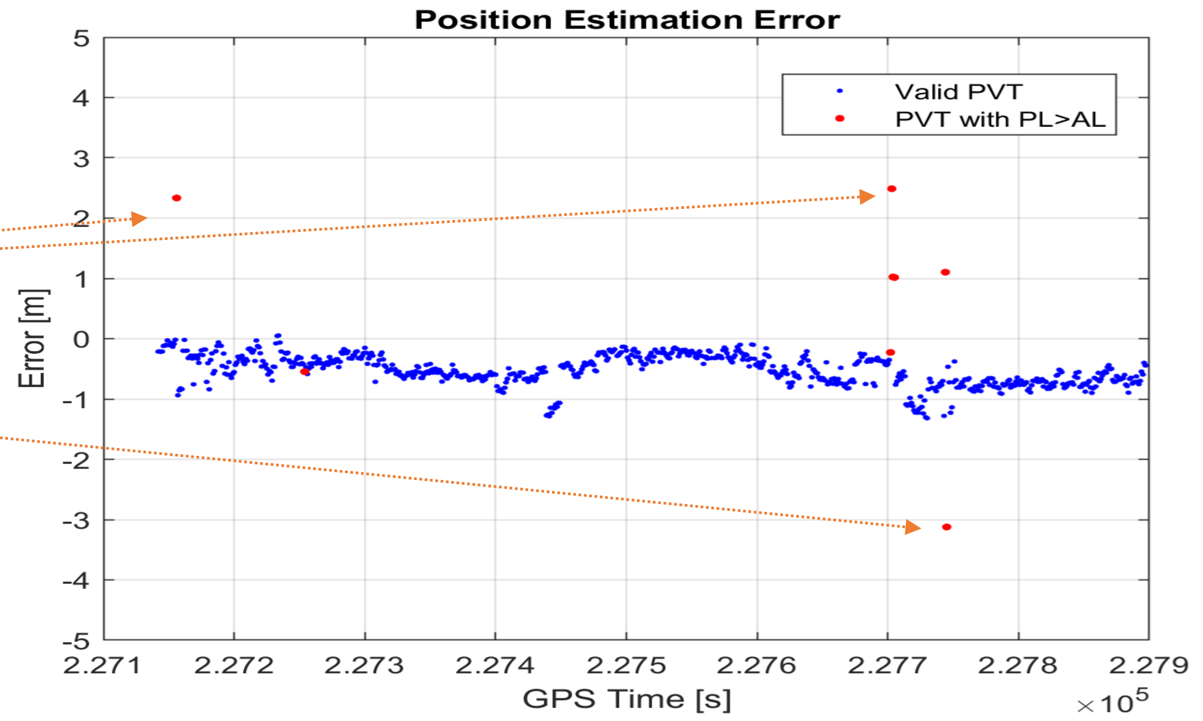
RTK Network (for track DB generation): HxGN SmartNet

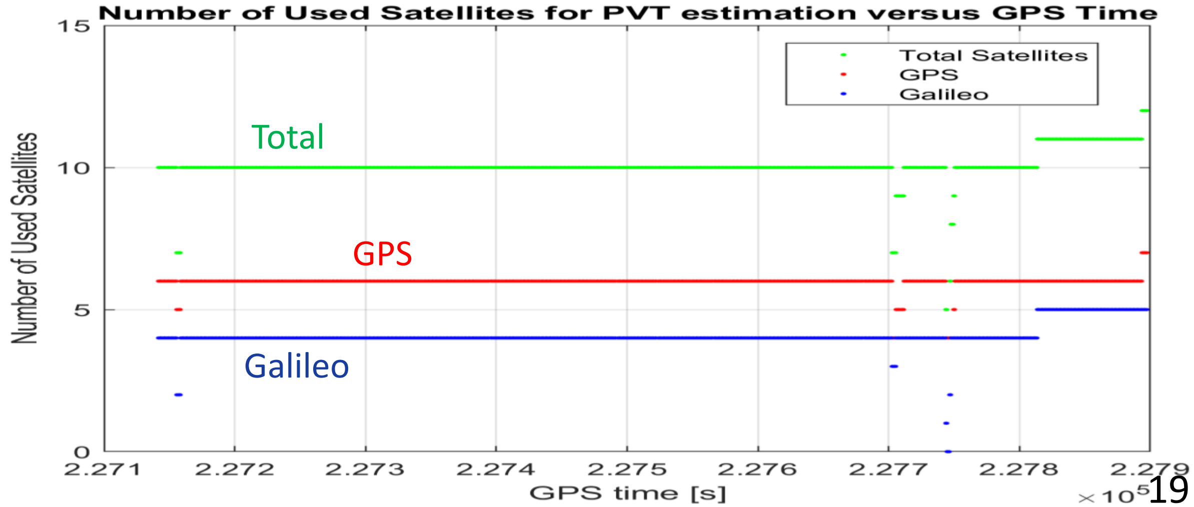
AIMN Network (real time): Sogei augmentation network.



EXPERIMENTAL RESULTS







SUMMARY & FINAL THOUGHTS

- HELMET combines multiple GNSS augmentation technologies to provide a coordinated solution for multiple user platforms and accuracy/integrity demands.

- GNSS positioning with high integrity for land mobile applications is challenging compared to aviation:
  - Liability mechanism (PNT vs Pseudorange)
  - Liability sharing (between service provider and application system integrator)
  - User interface: MOPS vs. SC-134 (certified receivers vs COTS)
  - Coverage (regional vs global)

- Existing and planned SBAS infrastructures are key to building robust GNSS service provisioning:
  - HELMET 2-tier architecture for rail and connected car applications reusing SBAS:
  - multi-modal approach to address a larger customer base sharing similar requirements
  - Different service levels – less-demanding ones are installed/tested/certified first
  - Local augmentation is scalable and deployable as a function of user demand

- Ongoing and future work
  - Integrity validation by demonstration of comprehensive threat mitigation
  - Development of certification plan and safety case for appropriate authorities

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Backup slides follow…

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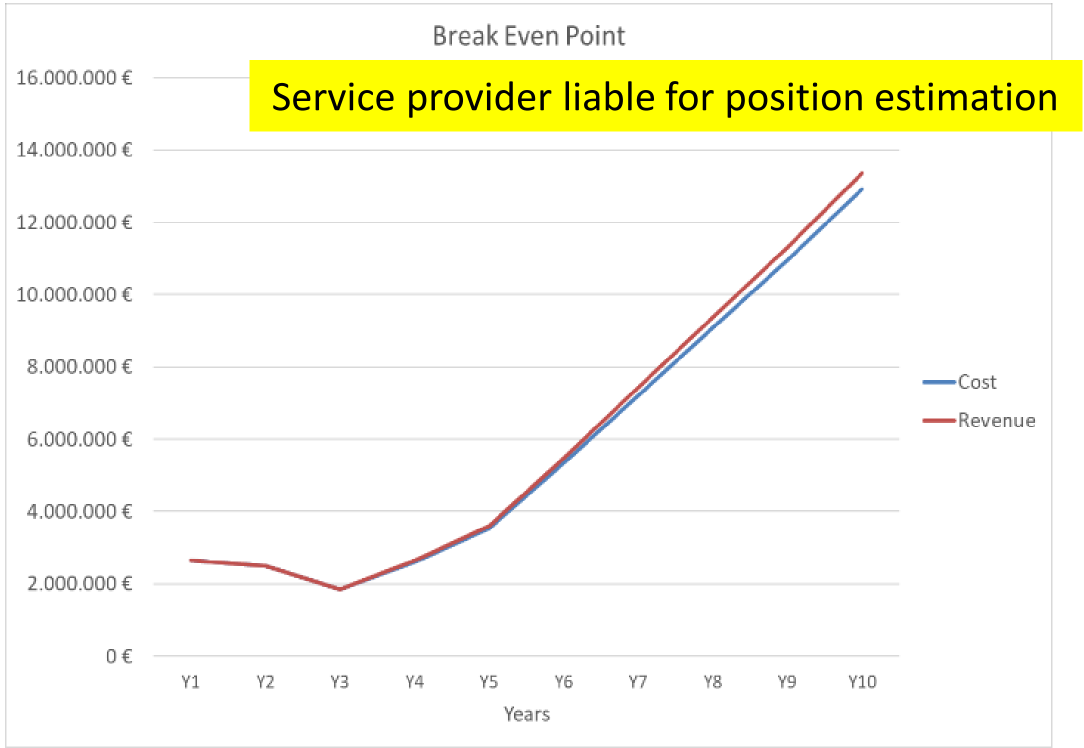
PRELIMINARY ECONOMIC ASSESSMENT

ASSUMPTIONS:

- Use EGNOS V2 (V3 when available) and build on top of it a local augmentation system
- Costs to deploy local elements shared between rail and roads infrastructure owners
- Service provider to sell Au data to Infrastructure managers who will broadcast to trains and cars
- Service provider funded at 100% (as for aviation) or at 50% are viable options to avoid direct public investment

Cost and revenue for a service provisioning including OBU – funding 100% of investment



Cost and revenue for an augmentation service – funding 50% of investment