agenzia spaziale italiana

ISTITUTO ITALIANO DI NAVIGAZIONE

RHINOS

"Railway High Integrity Navigation Overlay System"

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European Global Navigation Satellite Systems Agency

HORIZON 2020

GSA H2020 RHINOS Project

Railway High Integrity Navigation Overlay System

RadioLabs

Ansaldo STS

SOGEI

Stanford University

Nottingham University

Univerzita Pardubice

DLR Deutsches Zentrum Fuer Luft - Und Raumfahrt EV

Based on
- international cooperation between EU and USA

Objective
- a positive step beyond the proliferation of GNSS platforms, mainly tailored for regional applications, in favour of a global solution.

Work programme
- investigation of candidate concepts for the provision of the high integrity needed to protect the detected position of the train, as required by the train control system application.

Reference Infrastructure
- GNSS (GPS and GALILEO) plus the SBAS (EGNOS and WAAS)
- Local augmentation elements, ARAIM techniques and other sensors on the train are the add-on specific assets for mitigating the hazards due to the environmental effects which dominates the rail application.

Ambition
- Fast release of the potential benefits of the EGNSS in the fast growing train signalling market.

Project Objectives

- Objective 1: **To DEFINE THE ARCHITECTURE of a train Location Detection System (LDS) and of the supporting infrastructure**, with the following properties

  - **joint use of GPS and GALILEO** and wide area integration monitoring and augmentation networks (WAAS, EGNOS)
  - **standard interface** for providing Safety of Life services for railways through SBASs, regional augmentations or hybrid SBAS/GBAS systems;
  - compliance with European and US railway requirements and regulations;
  - **sharing** as much as possible of the **supporting infrastructure** and on board processing, including new developments such as ARAIM, with the **avionics** (and **automotive**) field,
  - provisioning of a set of functionalities tailored to the specific needs of the rail sector.

Project Objectives

- Objective 2: To assess the performance of the defined architecture by means of:

  - a PROOF-OF-CONCEPT integrating, in a virtualized testbed,
    - real railway environment data sets,
    - rare GPS SIS faults
    - simulated faults for the new constellations;

  - ANALYTICAL METHODS for verification and safety evidence of defined architecture according to railway safety standards (e.g. CENELEC EN 50129, etc.)

Project Objectives

- Objective 3: To contribute to the missing standard in the railway sector about the way of integration of GNSS-based LDS, into current Train Control System standards (e.g. ERTMS)

  - by publishing a comprehensive **GUIDE** on how to employ, in a cost-effective manner, GNSS, SBAS and other local infrastructures in safety related rail applications worldwide,

  - by defining a **STRATEGIC ROADMAP** for the adoption of an international standard based on the same guide.

Roadmap

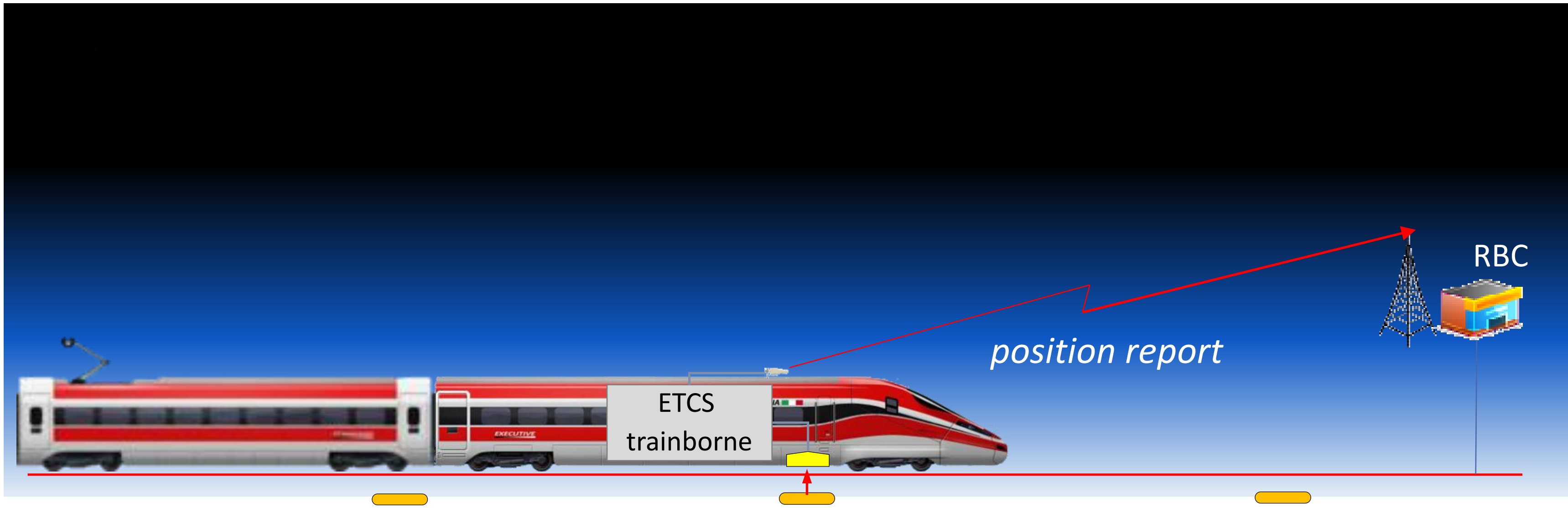
1. Revision of **requirements** and **functionalities** expected worldwide in the short, medium and long term, with specific emphasis to the European and US markets.
2. **Harmonization** between requirements and functionalities for **avionics** and **railways** applications.
3. Investigation of **candidate solutions** (augmentation and integrity monitoring infrastructures, and On Board Units)
   - evaluation of performance,
   - cost and benefits,
   - SWOT (Strength, Weakness, Opportunities, and Threats)
4. **Cost and Benefits trade-off** and selection of the reference architecture among the candidate solutions.
5. Realization of a **Proof of Concept**
6. Verification of the **reference architecture performance**
   - appropriate analytical methods and tools
7. Dissemination and consensus sharing.

- GNSS based train location determination can be considered a disruptive technology.
- It will succeed in replacing the current technologies based on balises and track circuits if and only if it will be COST-EFFECTIVE.

THR ≤ 10^{-9}/h

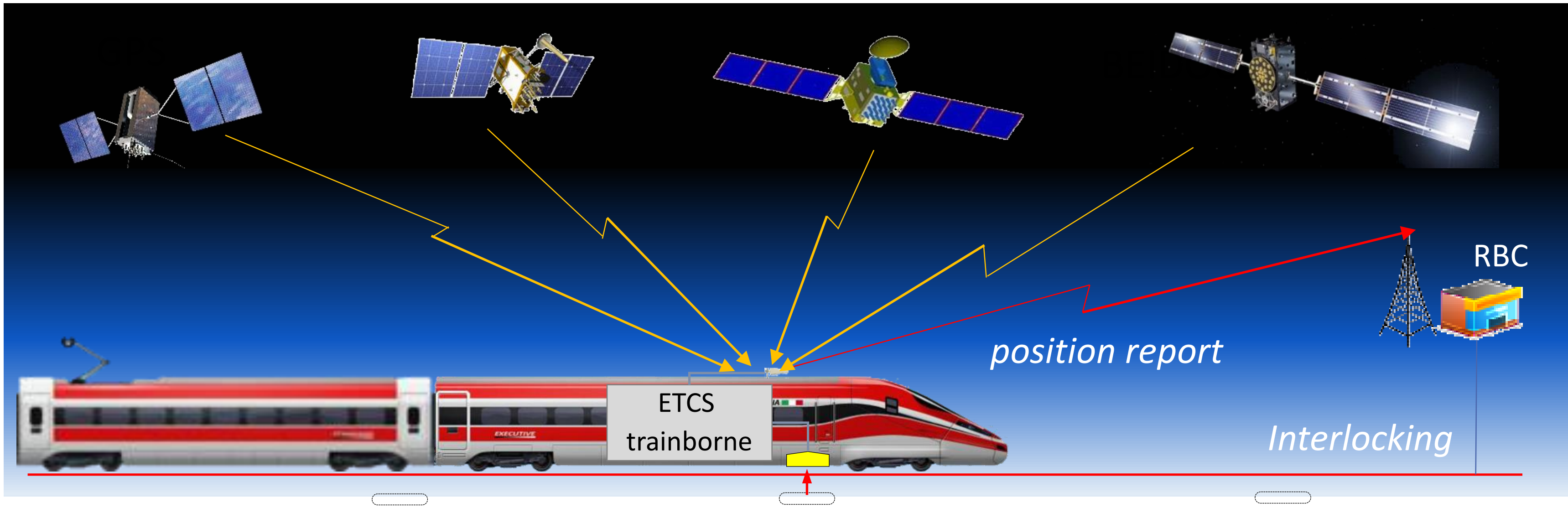
Functionality	Current EU Technology (ERTMS)	SIS Integrity Monitoring	Augmetation	**Accuracy**
Train Location Determination • Single track	Based on Balise	**X**	**X**	Medium
Train Location Determination • Multiple tracks	Based on Balise, Track Circuit	**X**	**X**	Medium, High
Train Integrity	Track Circuit + On Board Circuitry	**X**	N	High

ERTMS/ETCS Train Localization



Balise

- In ERTMS/ETCS Train location is determined by means of **Balises** and **Odometry**
- The Balises are transponders deployed at georeferenced points
- The odometer provides the relative positioning w.r.t. the last balise
- When the Balise Reader energizes a balise, it receives a message with the balise Id
- The on board computer sends a position report to the Radio Block Center

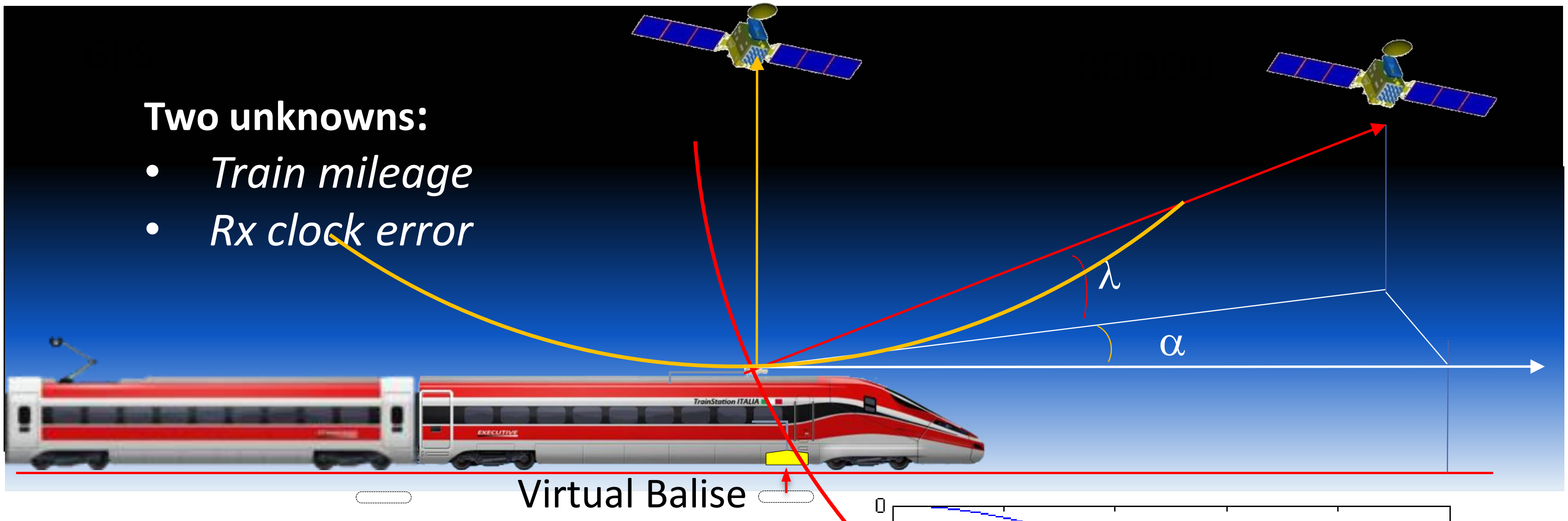


Virtual Balise

- 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 the Balise reader behavior with respect to the train equipment.

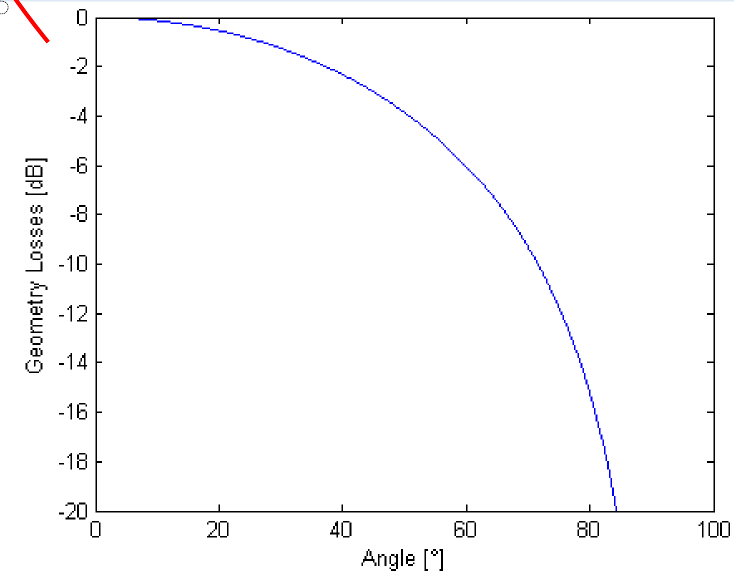
- In this way the On Board ERTMS/ETCS location determination functions do not need to be changed.

GNSS based Train Localization

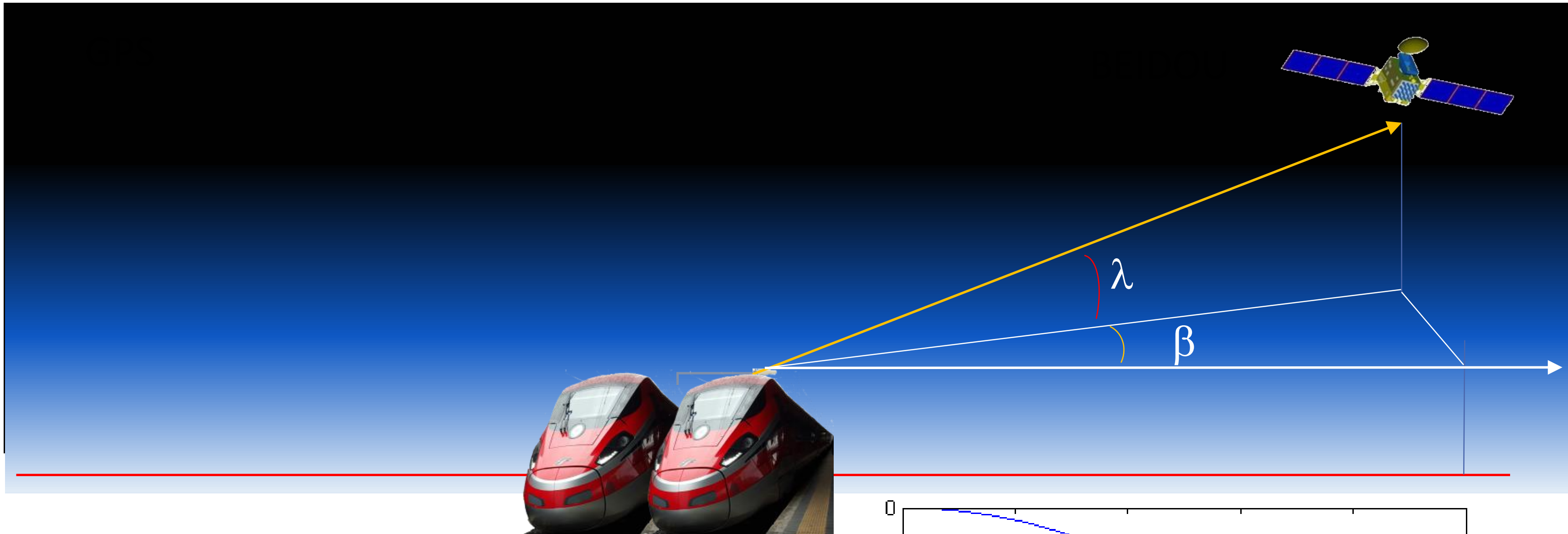


- The information carried by each satellite with respect to **the train mileage** depends on the relative geometry

$$J_s = J_r \cos^2 \alpha \cos^2 \lambda$$

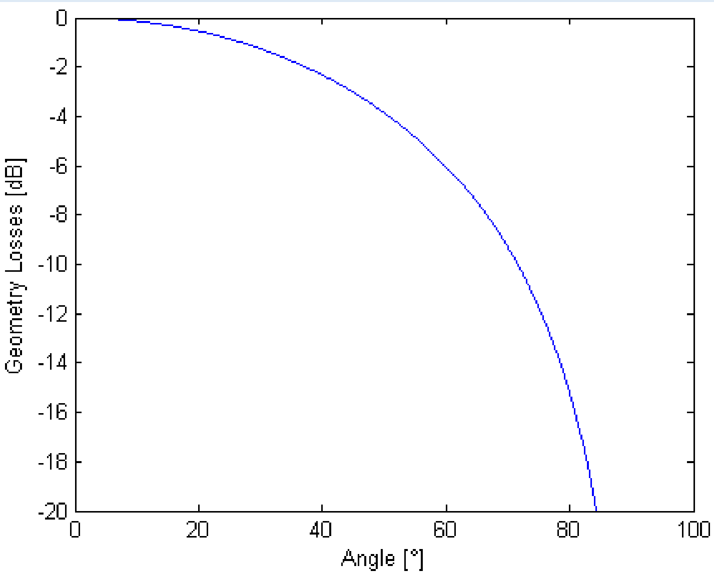


Multiple Tracks



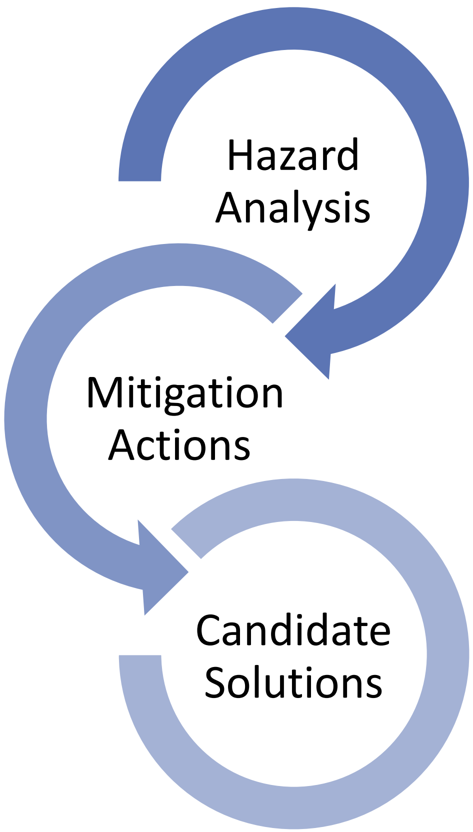
- The information carried by each satellite with respect to **multiple track discrimination** depends on the relative geometry

$$J_s = J_r \cos^2 \beta \cos^2 \lambda$$



Overlay Architecture

- Selection of candidate solutions concerning both augmentation and integrity monitoring infrastructures, and On Board Units starts from the mitigation actions related to the hazards identified during the Hazard Analysis



Hazards	Mitigations
Clock runoffs	SBAS & LADGNSS
Ephemeris Faults	SBAS & LADGNSS
Ionospheric storms	LADGNSS (multifrequency)
Signal Distortions	SBAS & LADGNSS
Constellation Rotations	SBAS & LADGNSS
Multipath	Train Autonomous Integrity Monitoring
Jamming, Spoofing	DBF + High Resilience DSP Train Autonomous Integrity Monitoring

NAVIGATION OVERLAY ARCHITECTURE

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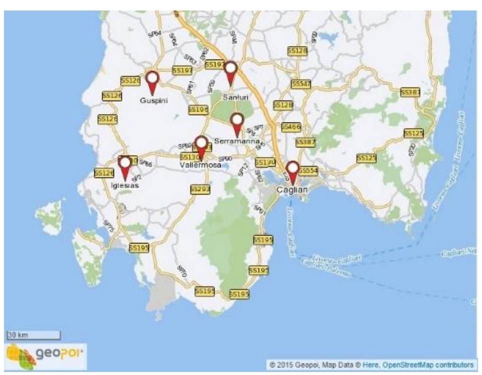
DRIVERS — ERTMS (SIL-4) requirements | Cost-effectiveness | Readiness

Shared with other services (Avionics, Automotive)

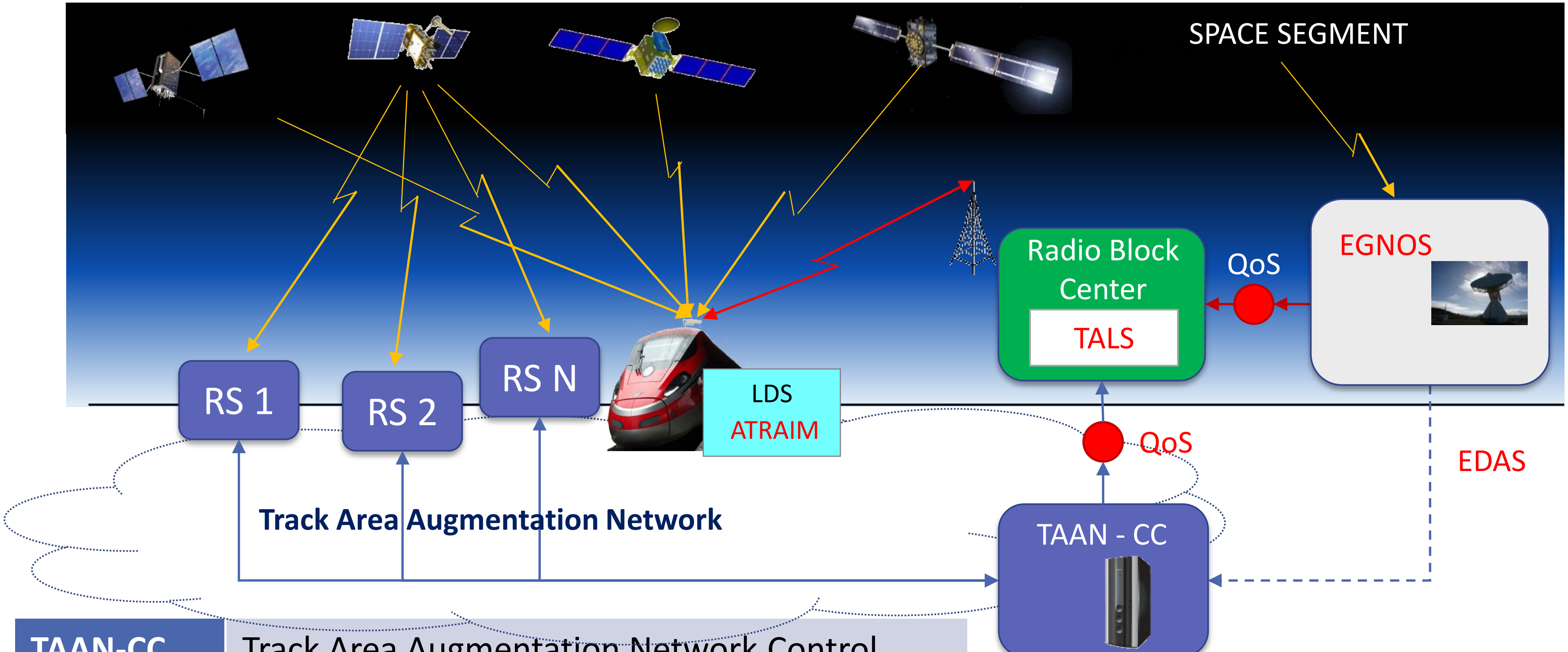
3 tiers Multiconstellation - Multifrequency System

- **1st tier:** Wide Area Differential Corrections and RIMS raw data trough dedicated link (EGNOS in EU, WAAS in U.S.A.)
- **2nd tier:** Track Areas Augmentation Network (TAAN) based on (low cost) COTS components
- **3rd tier:** Advanced Train Receiver Autonomous Integrity Monitoring



Health status of the 2nd tier as well as the integrity of the GNSS SIS is computed by joint processing of 1rst tier Wide Area Differential Corrections and 2nd tier RIM station data

NAVIGATION OVERLAY ARCHITECTURE



TAAN-CC	Track Area Augmentation Network Control Center
TALS	Track Area LDS Server
RS	Reference Station
EDAS	EGNOS Data Access Service
LDS OBU	Location Determination System On Board Unit

Local Hazards: Multipath

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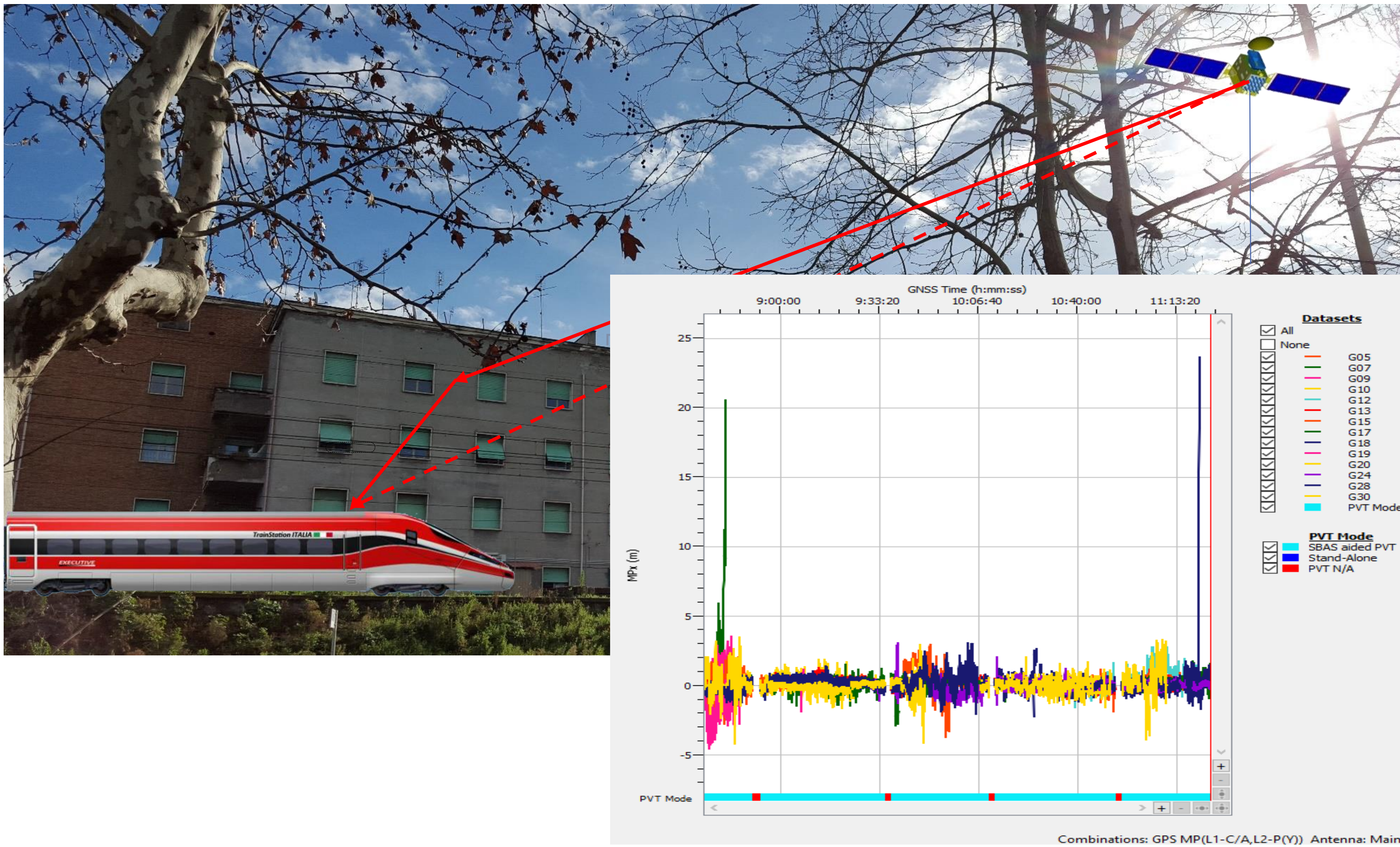

Local Hazards: Multipath

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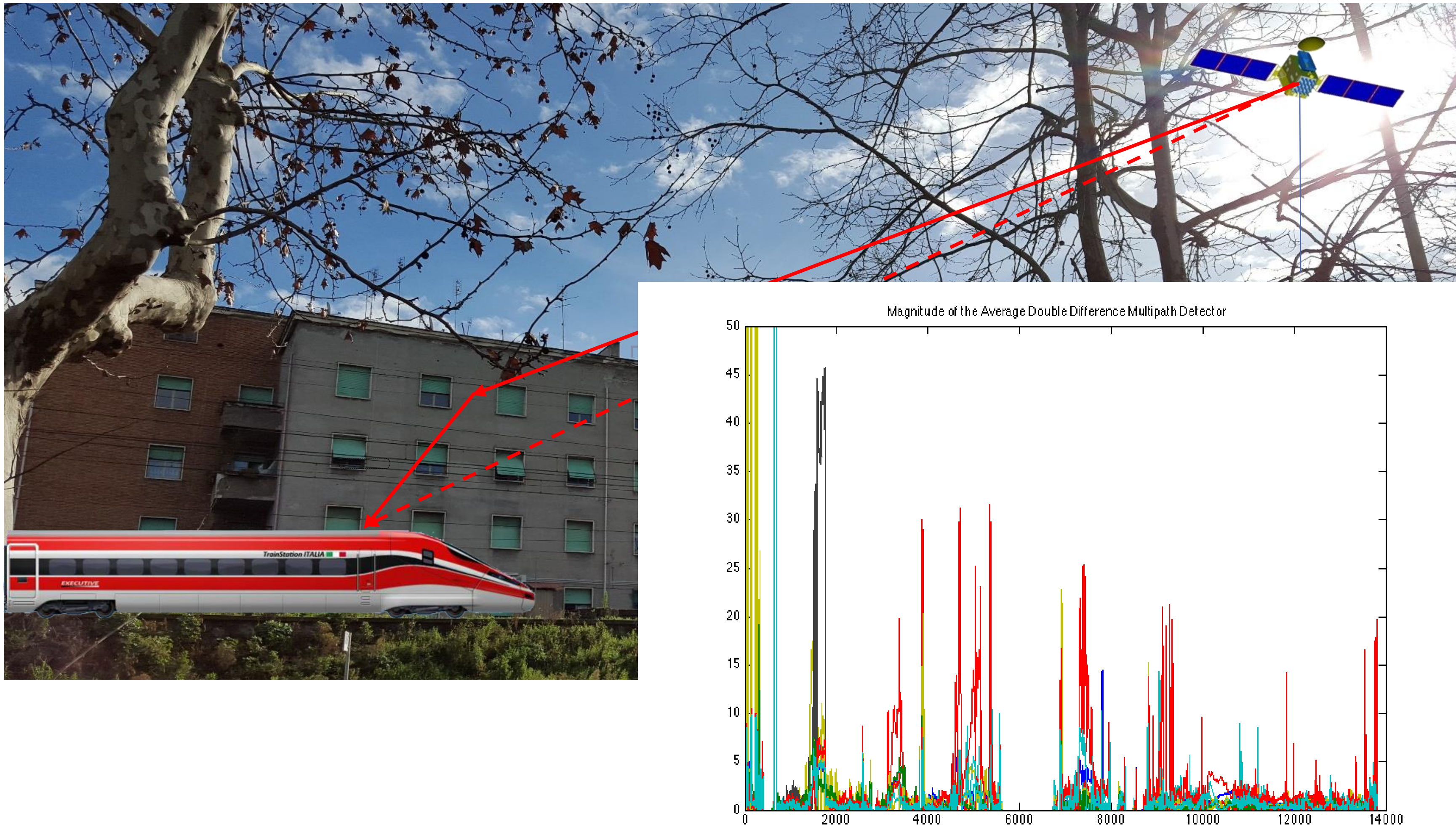
Local Hazards: Multipath



Multipath in rail environment

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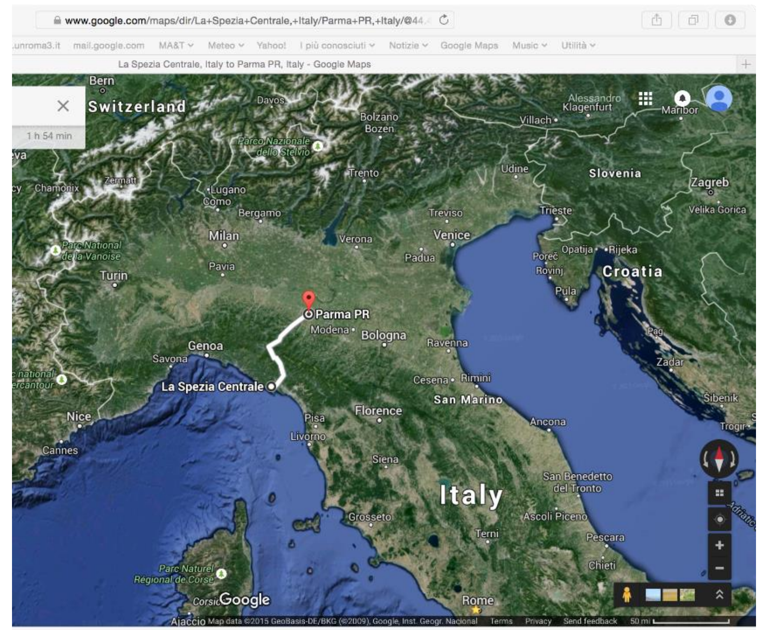
- Test campaign in the framework of the ESA ARTES 20 3InSat project

- PONTREMOLESE line
  - Line length: 120 km
  - Physical Balises: about 500
  - Track AreaAugmentation Network
    - 3 RIMs equipped with 2 GPS receivers each
  - Trains:
    - 2 Ale.642 tractions equipped with 2 GPS receivers each
  - Track Database based on RTK positioning survey



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  - Track Database based on RTK positioning survey
  - Challenging environment w.r.t. multipath
    - Tunnels
    - Sky occlusions

Given

- the train mileage estimated by the GNSS LDS at time t_h
- the distance travelled by the train during the interval $[t_h, t_k]$

the mileage of the train at time t_k can be computed as

$$\hat{s}(t_k;t_h) = \hat{s}_{GNSS}(t_h) + \Delta s_{OD}^{m}(t_h,t_k)$$

From the statistical independence of GNSS LDS and Odometer estimation errors it follows that the variance of estimate is

$$\sigma_{\hat{s}}^2(t_k;t_h) = \sigma_{s_{GNSS}}^2(t_h) + \sigma_{\Delta s_{OD}^{m}}^2(t_h,t_k)$$

$$\sigma_{\hat{s}}^2(t_k;t_h) \cong \sigma_{s_{GNSS}}^2(t_h) + \sigma_{\beta}^2(t_k - t_h)^2 + \sigma_{V_{OD}}^2(t_k - t_h), \qquad \alpha(t_k - t_h) \ll 1$$

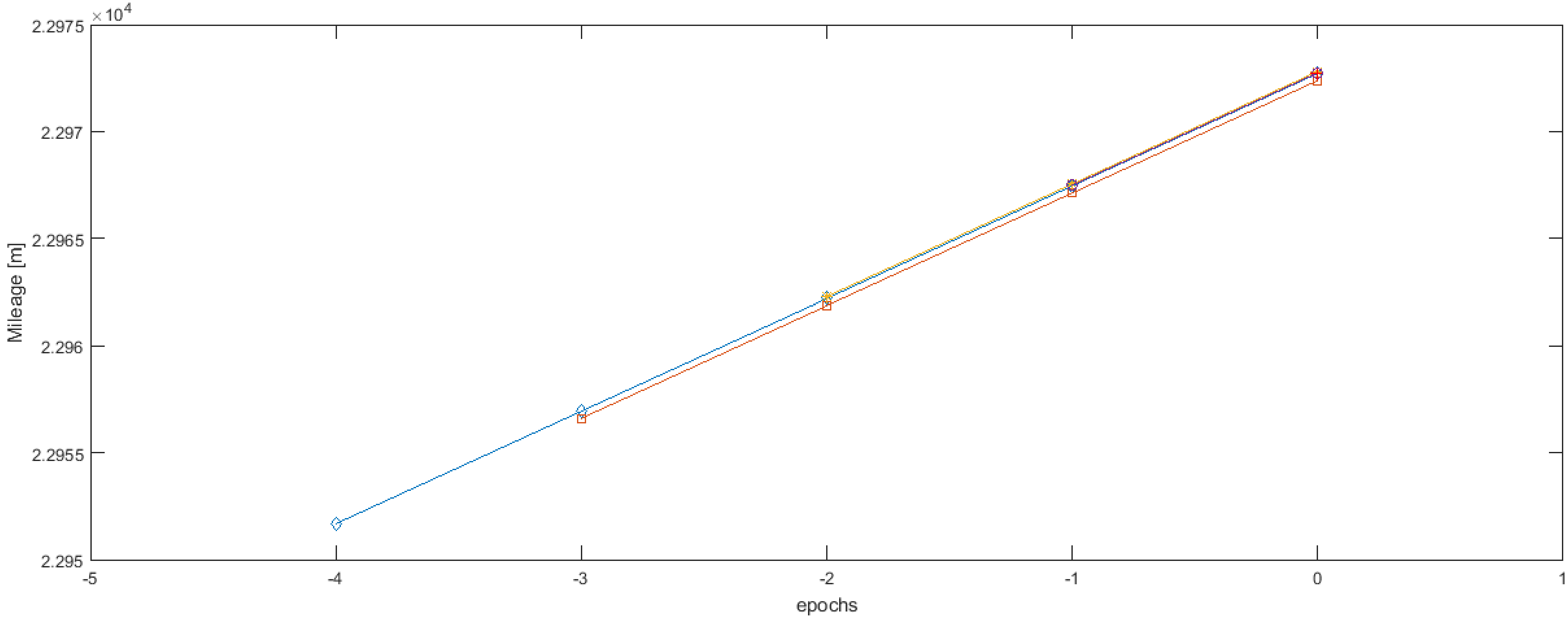
Protection Level (solution Separation Method)

$$PL_n(t_k;t_h) = k_{md,n}\sigma_{\hat{s}^{(n)}}(t_k;t_h) + \left|b_{Max}^{(n)}(t_h)\right| + \left|s_{GNSS}^{(0)}(t_h) - s_{GNSS}^{(n)}(t_h)\right|$$

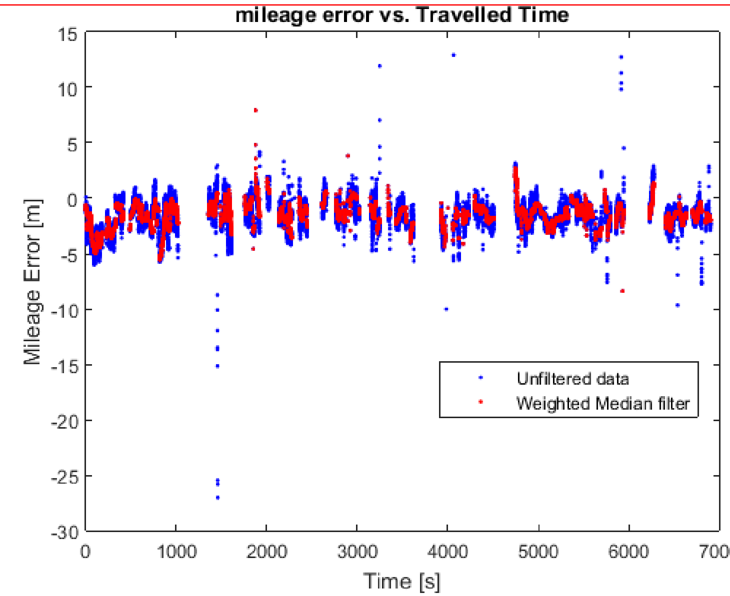
$$PL(t_k;t_h) = \underset{0 \le n \le N_F}{Max}\left\{PL_n(t_k;t_h)\right\}$$

Multipath Resilience

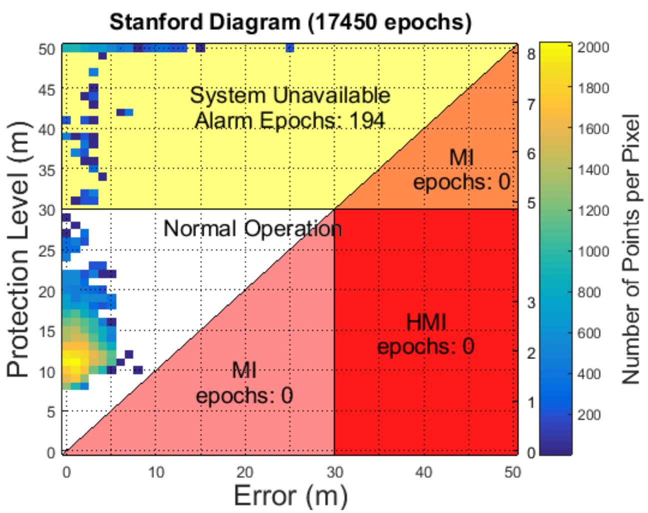
- In principle, for a given time instant t_k,several estimates can be performed by varying t_h in the interval $[t_k\text{-}\Delta t,\ t_k]$
- This redundancy can be exploited to filter out outliers produced by local hazards



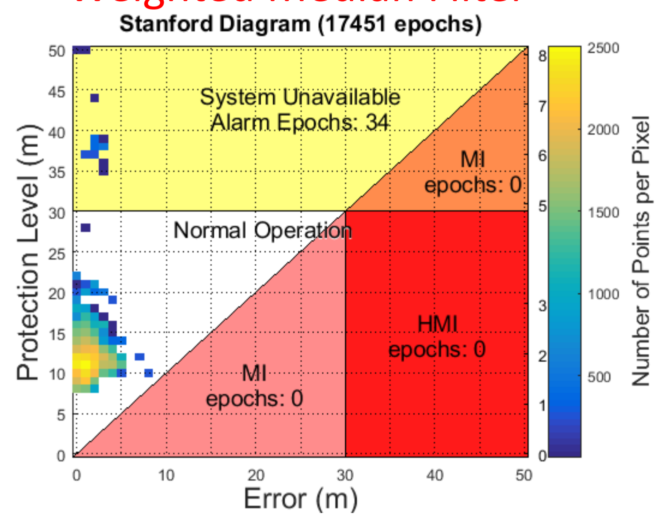
Multipath Resilience



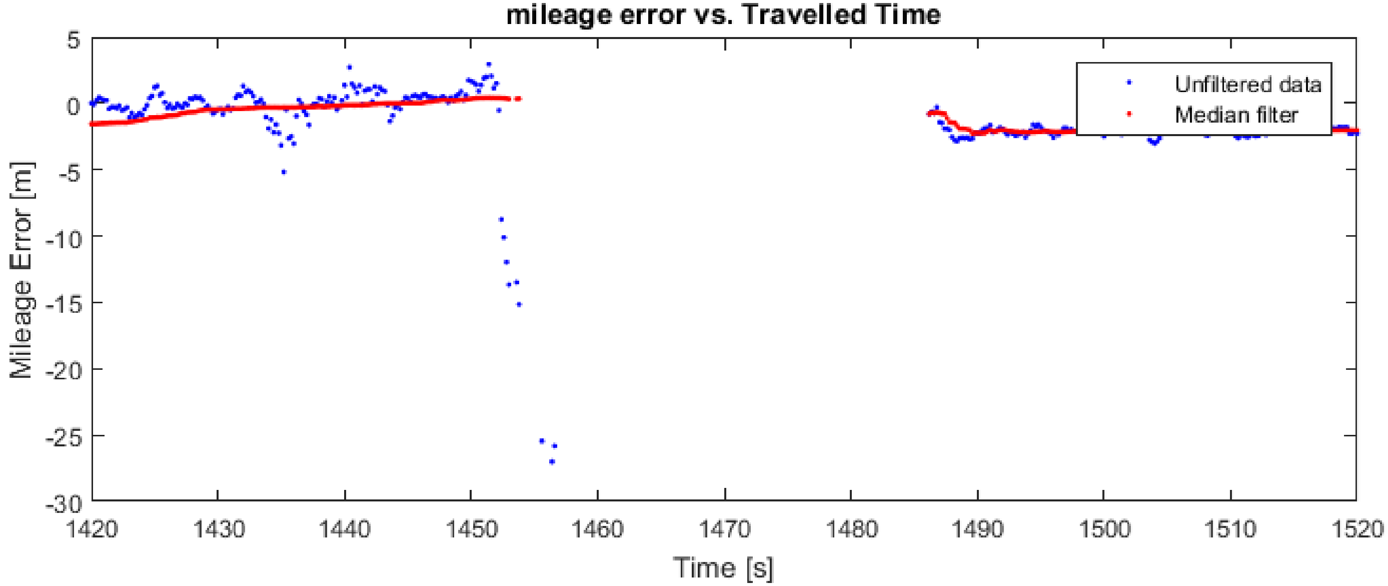
Unfiltered DATA

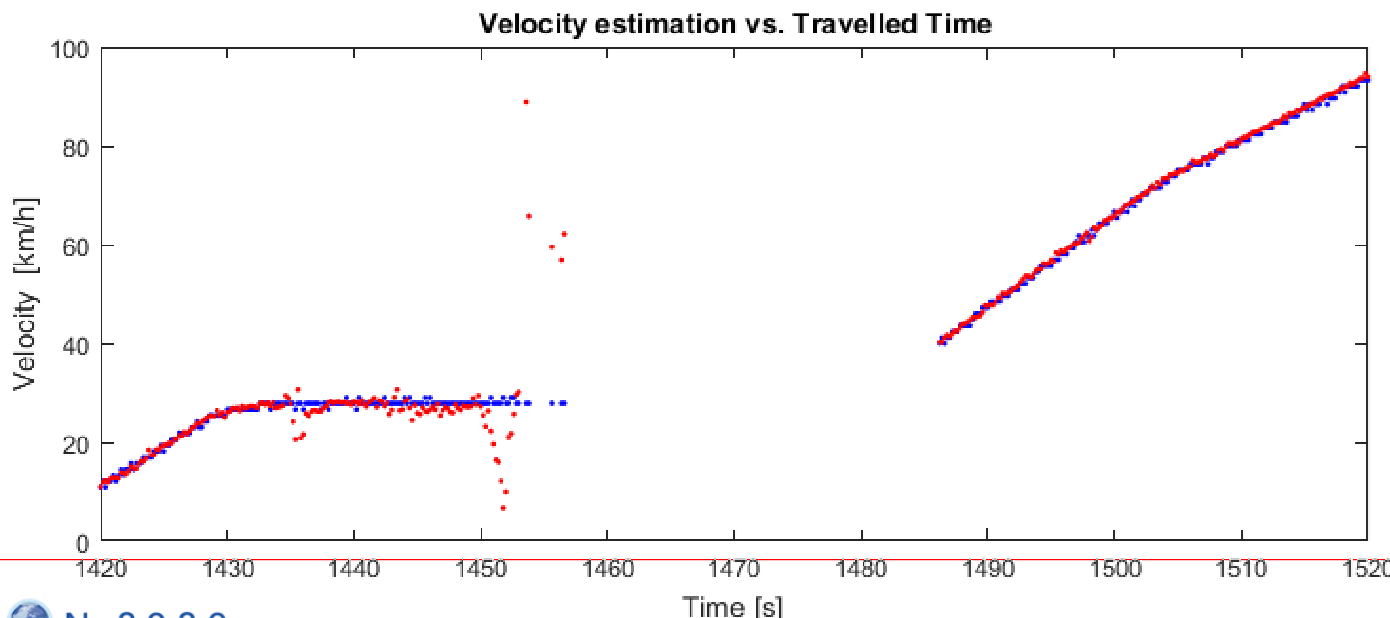


Weighted Median Filter



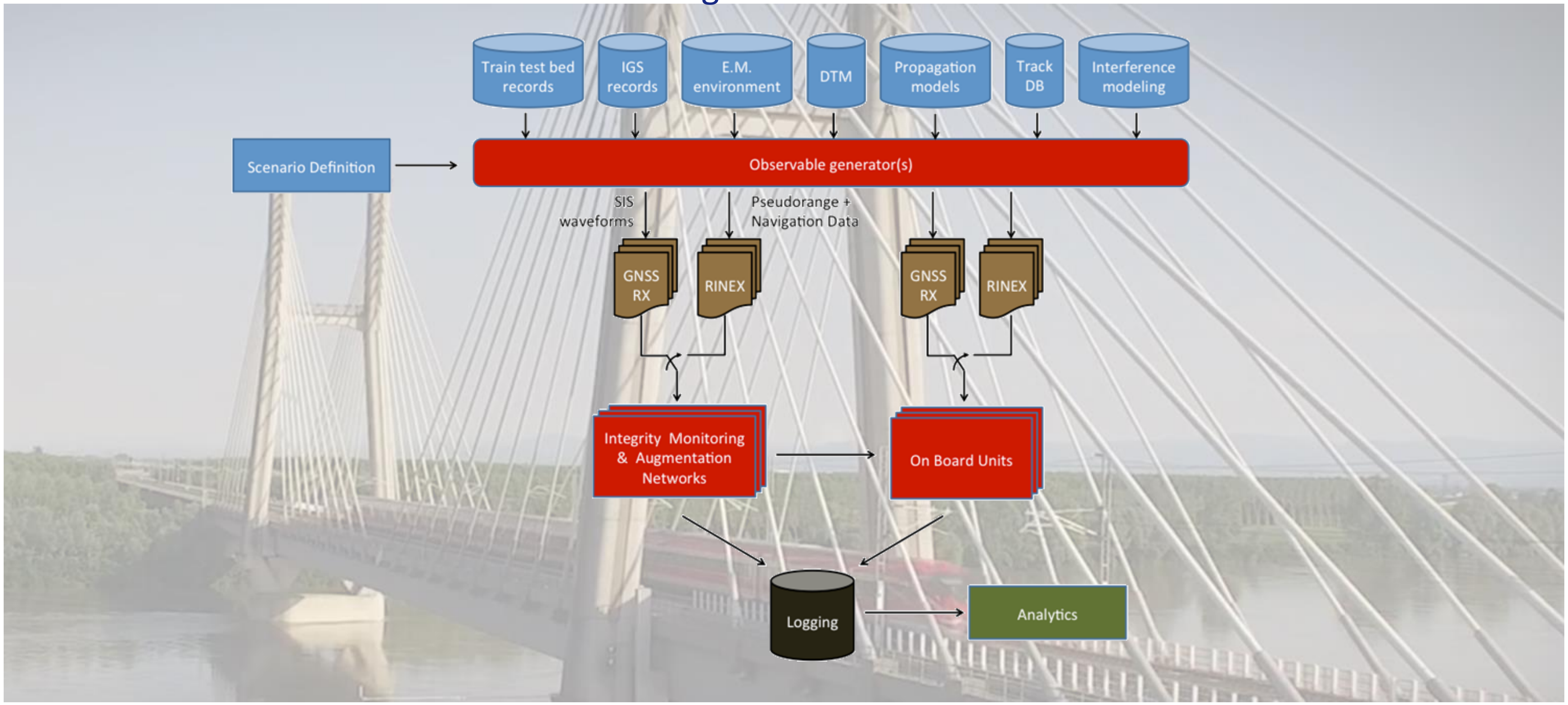
Advanced Integrity Monitoring





Performance Assessment: The Virtualized Testbed

- Assessing the performance of a Safety of Life system is a rather challenging task due to the fact that very small probabilities are involved.
- Approach: virtualized testbed, with
  - rich sets of data collected in a real railway environment (e.g., 3InSat & ERSAT EAV Test Bed),
  - historical time series related to rare GNSS SIS fault events (satellite malfunctions and atmosphere anomalous behaviors)
  - simulated faults for the new-coming constellations



Conclusions

- MULTI-CONSTELLATION architectures offer higher degree of flexibility to reach the SIL-4 level (recommended for high demanding accuracy in the railways applications).
- Nevertheless, the availability of an augmentation network is of paramount importance in reducing the Protection Level.
- Definition of a standard for the Railway High Integrity Navigation Overlay System is a key success factor for spreading the GNSS application into the rail.
- SHARING OF SUPPORTING INFRASTRUCTURE (i.e., augmentation) and on board processing as much as possible , including new developments such as Advanced Receiver Autonomous Integrity Monitoring (ARAIM), with AVIONICS and AUTOMOTIVE fields is a key factor for cost effectiveness.
- Definition of a strategic roadmap for the adoption of a COMMON procedure for High Integrity Application CERTIFICATION is of primary concern.

THANKS FOR YOUR ATTENTION