Pacific PNT
May 2-4, 2017
Honolulu, Hawaii

ERSAT - EAV

ERTMS on SATELLITE – Enabling Application Validation

Alessandro Neri[1], Gianluigi Fontana[2], Salvatore Sabina[2], Francesco Rispoli[2],
Roberto Capua [3], Giorgia Olivieri[3], Fabio Fritella[3], **Andrea Coluccia[1]**, Veronica Palma[1], Cosimo Stallo[1], Alessia Vennarini[1]

[1] RADIOLABS, Rome Italy
[2] Ansaldo STS Genoa Italy
[3] SOGEI S.p.A., Italy

Ansaldo STS A Hitachi Group Company

ERSAT – EAV

Contents

- Introduction
- ERSAT-EAV architecture
- Sardinia test bed description
- Experiment description
- Experimental results
- Conclusions

ERSAT – EAV

Introduction

ATP

legacy Automatic Train Control

ERTMS/ETCS

The European Rail Traffic Management System/ European Train Control System

STRENGHTS

CAPACITY

PERFORMANCE

SAFETY

Challenges

Economical Sustainabiity for Local-Regional lines

ERSAT – EAV

Introduction

Determination of train location in GNSS-based ERTMS/ETCS level 2

Eurobalises – BTM

⊕

Odometry

Provides in output

Estimate of the travelled distance

+

accuracy

ERSAT – EAV Project

Virtual Balises – Virtual Balise Reader

⊕

Odometry

Provides in output

Estimate of the travelled distance

+

accuracy

ERSAT – EAV

Introduction

Determination of train location in GNSS-based ERTMS/ETCS level 2

Functionality: TRACK DISCRIMATION

Requirements:

- *Accuracy required = a few decimeters*

Interaxis between two adjacent track = 3 m

- *Tolerable Hazard Rate (THR) = 10^{-9} during hour of operation*

to be compliant at safety Integrity Level 4 (SIL-4) defined in CENELEC Norms

GNSS-based LDS: Global hazard mitigation is necessary

Ephemeris errors
Satellite clock runs-offs
Ionospheric storms
Tropospheric anomalous

ERSAT – EAV

Introduction

ERSAT-EAV project objective …

To verify the suitability of GNSS as the enabler of cost-efficient and economically sustainable ERTMS signaling solutions for safety railway applications.

ERSAT-EAV solution exploits …

the advantages of the multi-constellation approach and of EGNOS and Galileo services, providing an optimized augmentation service to the trains, in order to meet the severe railway requirements on safety.

The objective of this work …

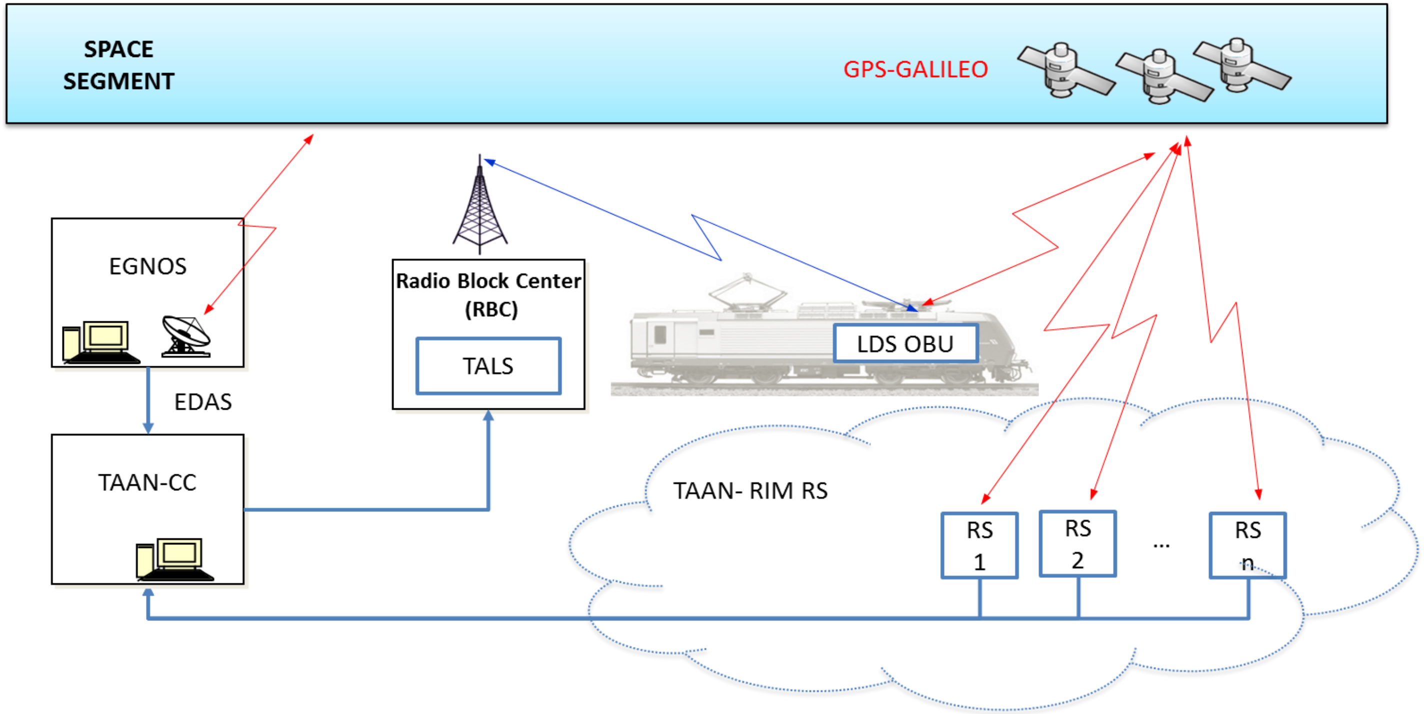
to test the ERSAT-EAV multiconstellation capability

ERSAT – EAV

Architecture

Two tiers 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



Ansaldo STS A Hitachi Group Company · Università Bocconi · ceit · DB Netze · DLR · ESSP · RadioLabs · RFI Rete Ferroviaria Italiana · sogei · Telespazio · Trenitalia

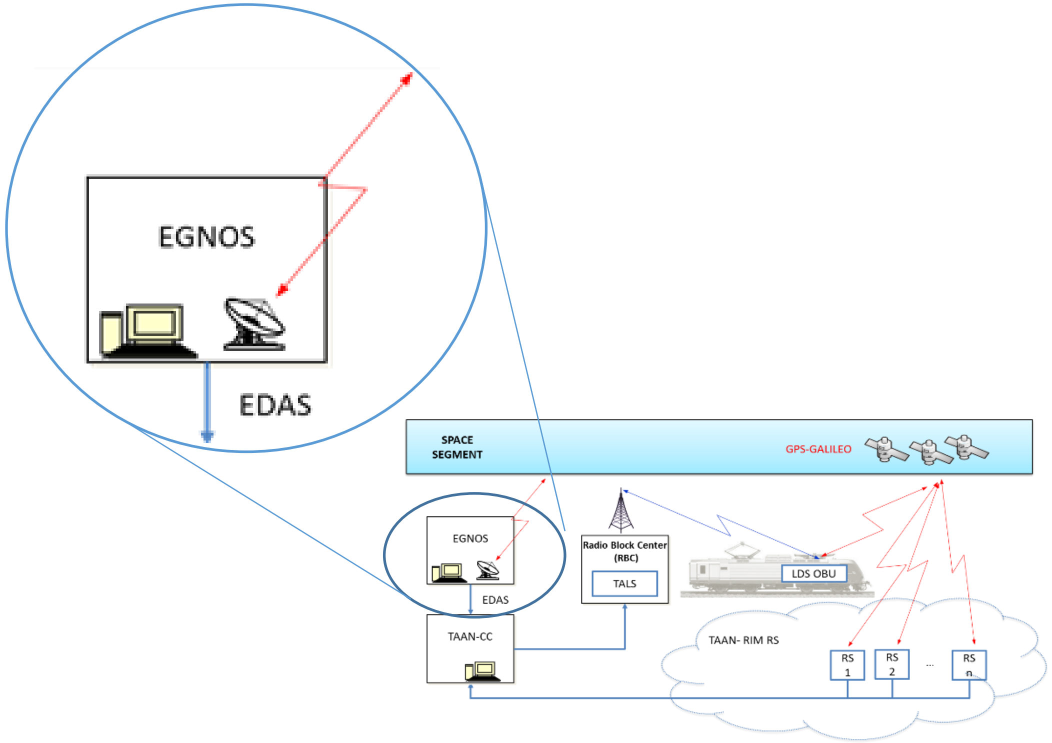
ERSAT – EAV

Architecture - 1st Tier

The **EGNOS services** are a **input for the 2nd tier**.

Exist two kind of EGNOS services:

1. SoL (Safety of Life) EGNOS SIS
2. EDAS (EGNOS Data Access Service)



The **SoL EGNOS signal** broadcasts the following information:

- GNSS satellite status;
- Precise GNSS satellite ephemeris and clock corrections;
- Ionospheric corrections (*Grid Ionospheric Vertical Error* – GIVE).

ERSAT – EAV

Architecture - 1st Tier

The **EDAS** is the terrestrial EGNOS data service the following information:

- GNSS raw data;
- The EGNOS augmentation messages;
- Differential GNSS (DGNSS) and RTK (Real-Time Kinematic) messages.

Table 1 EDAS services data in Real Time (Service Level 0, Service Level 2), SISNeT (Signal in Space through the Internet), NTRIP (Networked Transport of RTCM via Internet Protocol)) and Archive (FTP (File Transfer Protocol)).

Mode	EDAS Service	Type of Data				Transmission Protocol	Formats
		Observation & navigation	EGNOS messages	RTK corrections	DGNSS corrections		
Real Time	Service Level 0	X	X			EDAS	ASN.1
	Service Level 2	X	X			EDAS	RTCM 3.1
	SISNeT		X			SISNET	RTCA DO-229D
	NTRIP	X		X	X	NTRIP v2.0	RTCM 2.1, 2.3, 3.1
Archive	FTP	X	X			FTP	RINEX 2.11, RINEX B 2.10, EMS, IONEX, SL0 and SL2

Table 2 EDAS services availability commitment

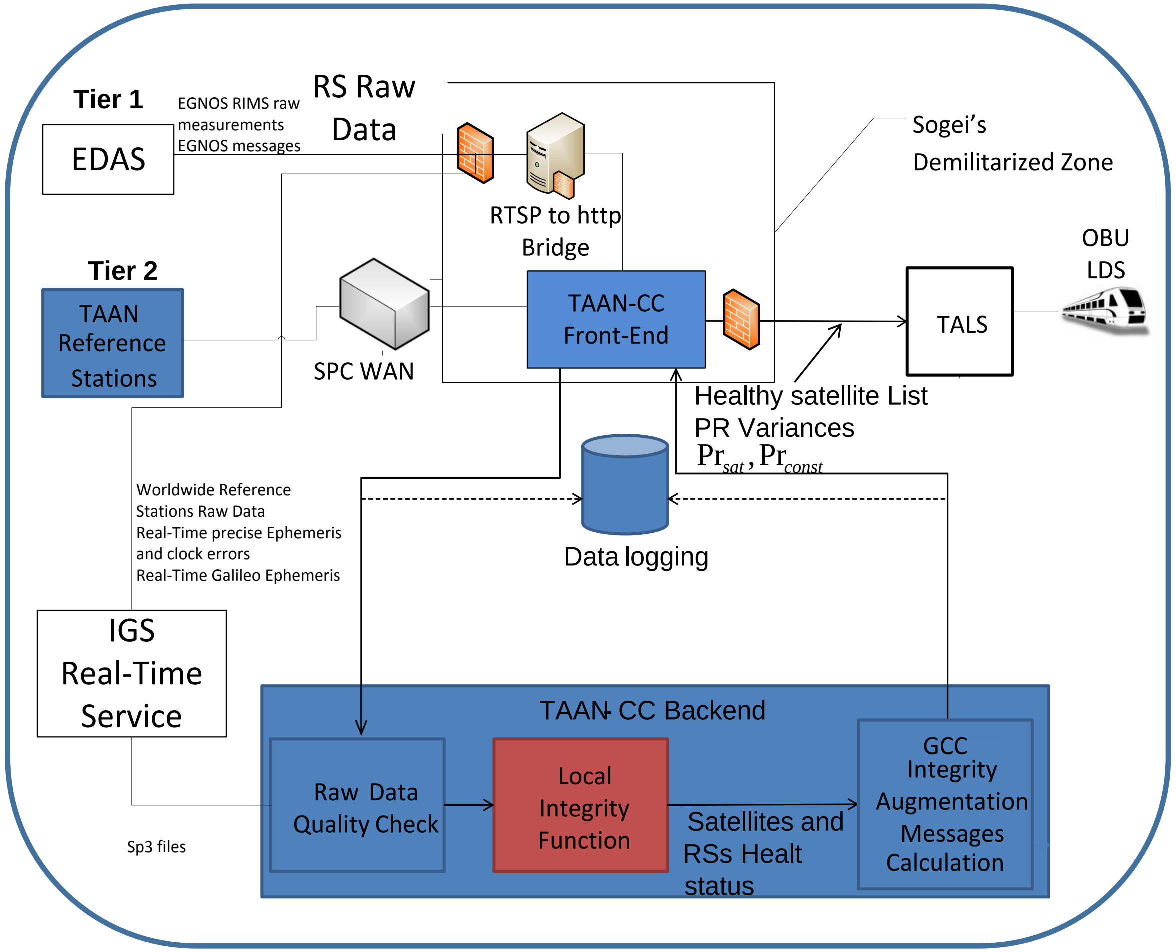
	Service Level 0	Service Level 2	SISNeT	Ntrip	Data Filtering	FTP
EDAS Services Availability	98.5%	98.5%	98%	98%	98%	98%

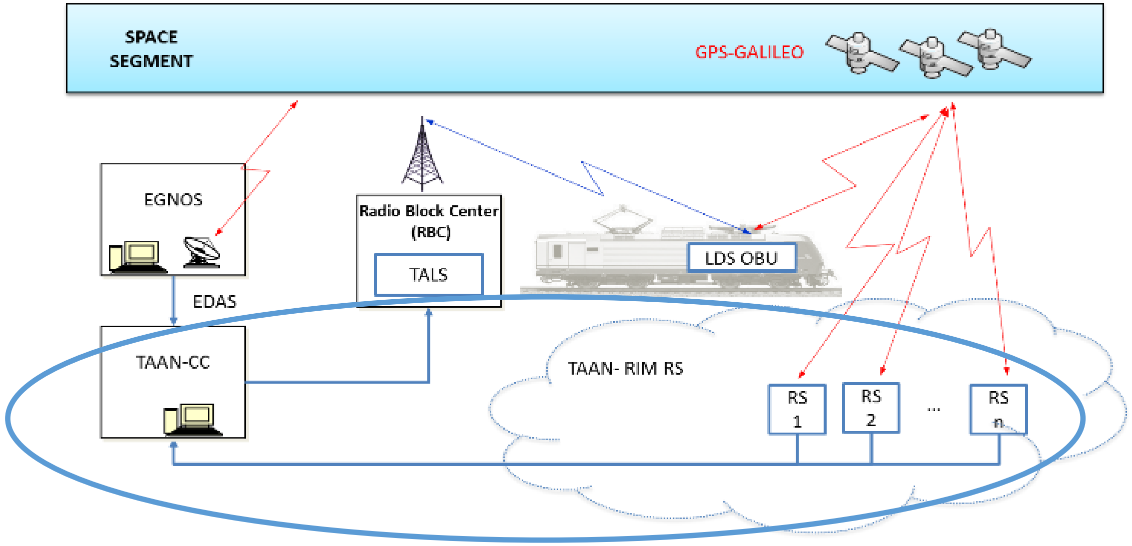
Table 3 EDAS services latency commitment

	Service Level 0	Service Level 2	SISNeT	Ntrip	Data Filtering		FTP
					Service Level 0	Service Level 2	
EDAS Services Latency	1.3 seconds	1.450 seconds	1.150 seconds	1.75 seconds	1.6 seconds	1.75 seconds	N/A

ERSAT – EAV

Architecture – 2nd Tier





Ansaldo STS A Hitachi Group Company · Università Bocconi · ceit · DB NETZE · DLR · ESSP · RadioLabs · RFI Rete Ferroviaria Italiana · sogei · Telespazio · Trenitalia

ERSAT – EAV

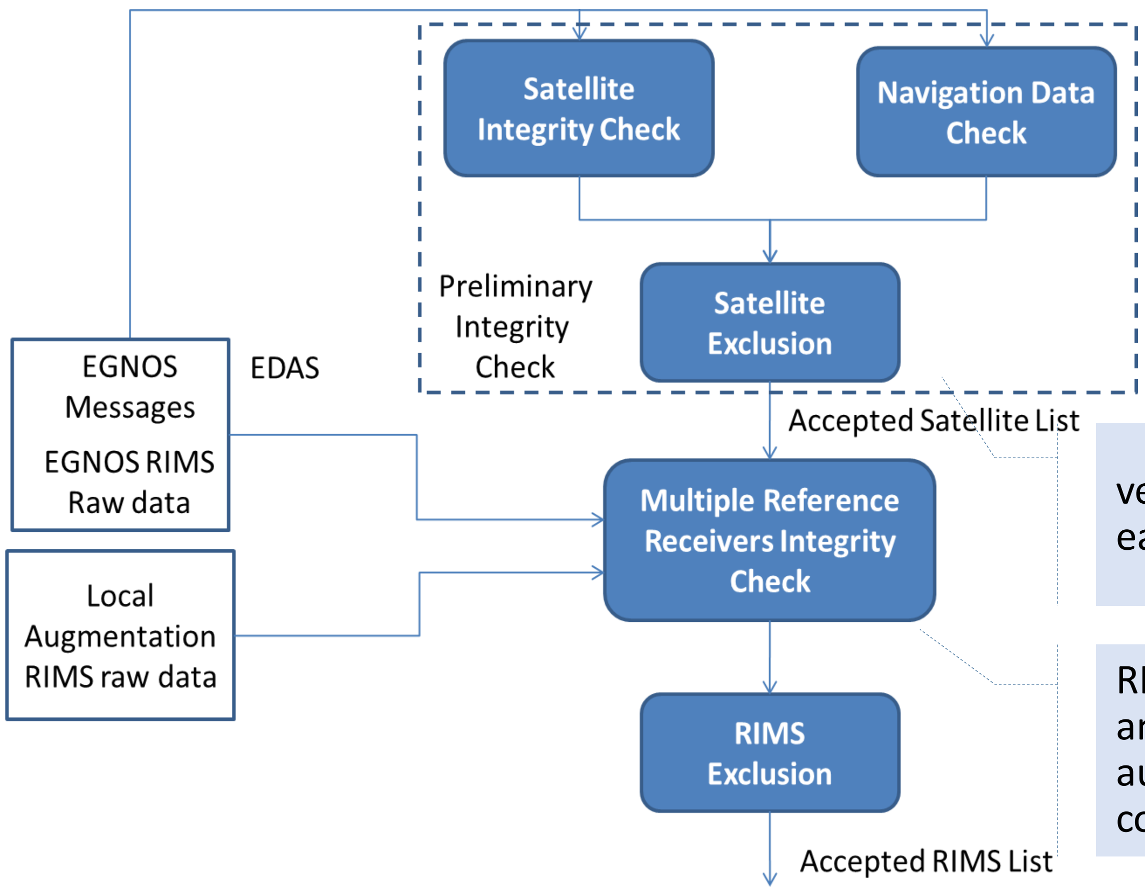
TAAN – Local Integrity Function (LIF)

The **LIF** of the TAAN-CC implements a **Fault Detection and Exclusion algorithm**

Two level of integrity check:

1. Preliminary Integrity Check
2. Multiple Reference Receivers Integrity Check

- Single satellite faults
- Constellation faults
- RIM faults



verifies health status of each SIS at RIM level.

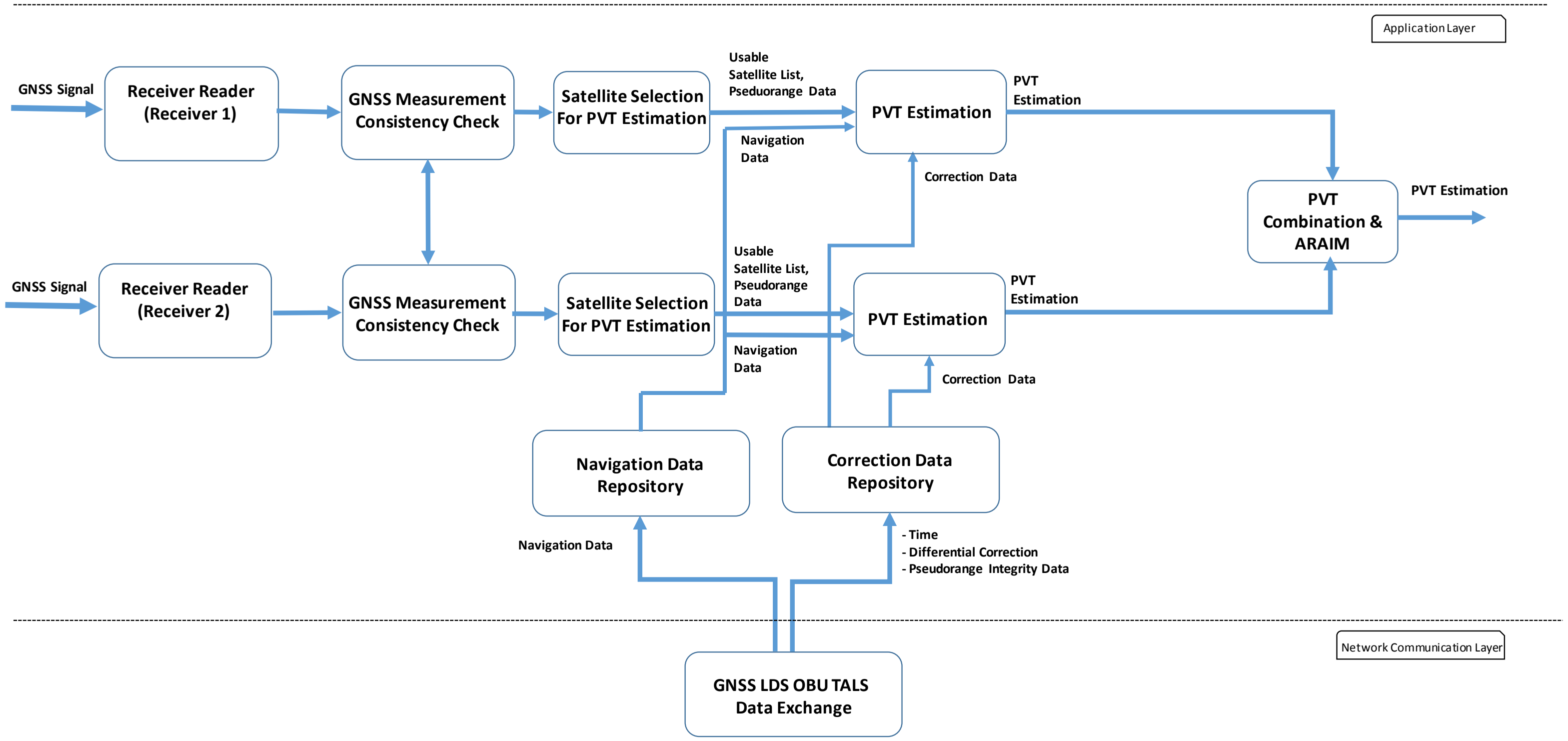
RIM Faults detection and exclusion from augmentation computation

ERSAT – EAV

Architecture – GNSS Based LDS OBU

Each GNSS-Based LDS OBU is defined by:

1. Two GNSS receivers;
2. Digital trackmap database;
3. A local processor performing:
   - Signal-In-Space Recevier and decode
   - GNSS Measurement Consistency Check
   - Satellites Selection for PVT Estmation
   - PVT estimation
   - ARAIM (Advanced Reciver Autonomous Integrity Monitoring)



ERSAT – EAV

Architecture – GNSS Based LDS OBU

The Fisher's information of **the train mileage** is

$$J_s = \frac{1}{\sigma_\rho^2}\cos^2\alpha\cos^2\lambda \qquad (1)$$

$$\sigma_{\Delta s}^2 = \frac{c^2}{4\pi^2 \overline{f^2}} \frac{\sum_{i=1}^{N_{Sat}} SNR_i}{\sum_{i=1}^{N_{Sat}} SNR_i \sum_{i=1}^{N_{Sat}} SNR_i \cos^2\alpha_i \cos^2\lambda_i - \left[\sum_{i=1}^{N_{Sat}} \cos\alpha_i \cos\lambda_i SNR_i\right]^2} \qquad (2)$$

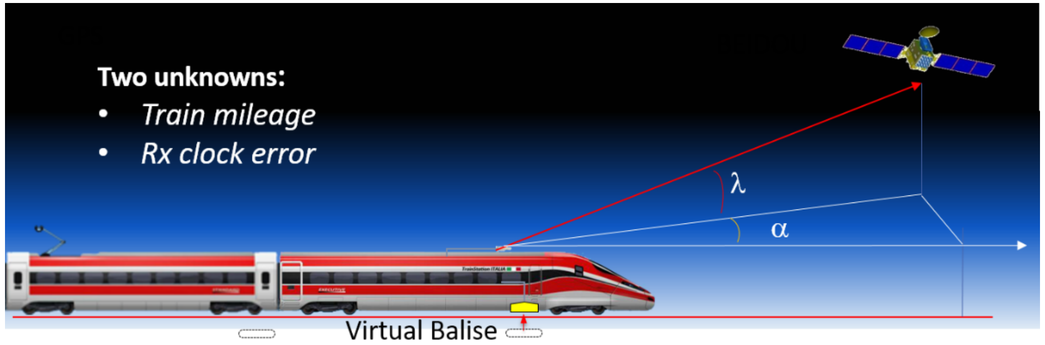


Figure 4. Fisher's information for Train mileage estimation geometry

The Fisher's information for **track discrimination** is

$$J_s = \frac{1}{\sigma_\rho^2}\cos^2\beta\cos^2\lambda \qquad (3)$$

where $\beta = \frac{\pi}{2} - \alpha$

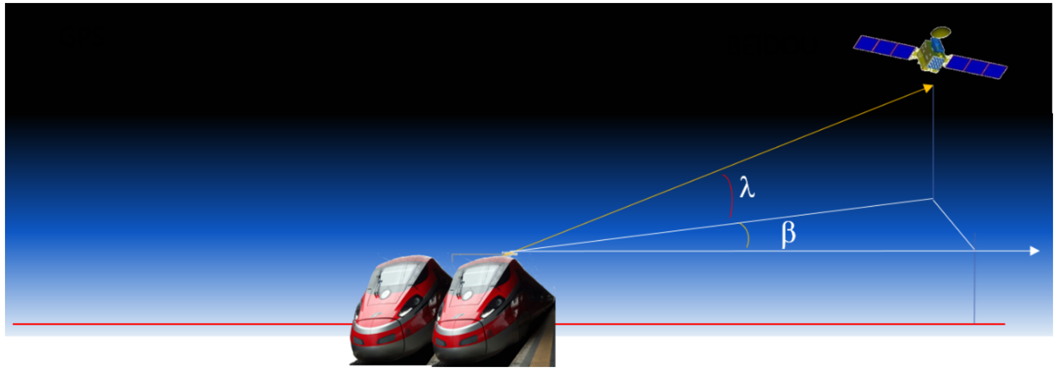


Figure 5. Fisher's information for track discrimination geometry

Ansaldo STS A Hitachi Group Company · Università Bocconi · ceit · DB NETZE · DLR · ESSP · RadioLabs · RFI Rete Ferroviaria Italiana Gruppo Ferrovie dello Stato Italiane · sogei · Telespazio A Finmeccanica/Thales Company · Trenitalia Gruppo Ferrovie dello Stato Italiane

ERSAT – EAV

Architecture – GNSS Based LDS OBU

PVT Combination module

$$Combined\_Est = \lambda_1 * D_{est_1} + \lambda_2 * D_{est_2}$$

$$Combined\_Train\_Speed = \lambda_1 * Speed\_1 + \lambda_2 * Speed\_2$$

where

D_{est_1}, zero train mileage estimate based on Rx_1 pseudoranges

D_{est_2}, zero train mileage estimate based on Rx_2 pseudoranges

$Speed\_1$, Velocity Estimate by Rx1

$Speed\_2$, Velocity Estimate by Rx2

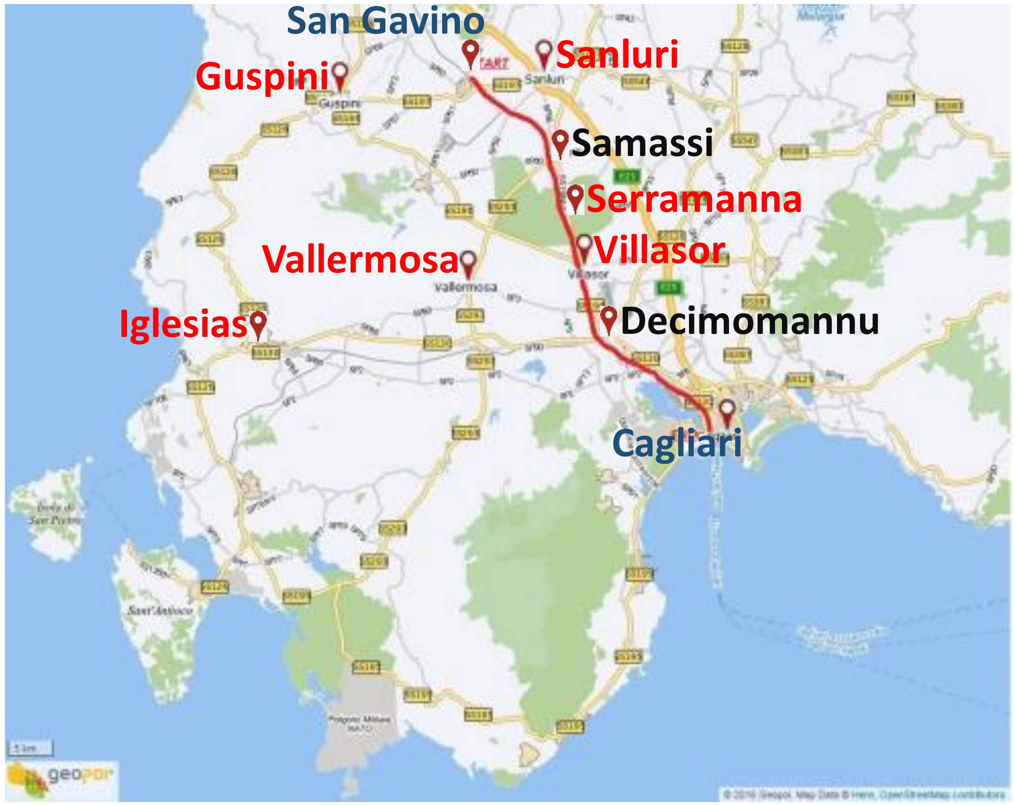
$\lambda_2 = \dfrac{\sigma_1^2}{\sigma_1^2 + \sigma_2^2}$, with σ_1 the standard deviation of Estimate by Rx1 and σ_2 the standard deviation of Estimate by Rx2

ERSAT – EAV

SARDINIA TEST BED

The SARDINIA testbed for the ERSAT-EAV Project

- ✓ ROUTE
  - Cagliari – San Gavino (about 50 Km) (owned by the Rete Ferroviaria Italiana)
- ✓ 1st Tier
  - EGNOS (owned by the European Union)
- ✓ 2nd Tier:
  - Private Local Area Augmentation Network (owned by the Ansaldo STS)
  - Public Local Area Augmentation Network (owned by the SOGEI)
- ✓ TALS located in Radio Block Center (RBC) (owned by the Ansaldo STS)
- ✓ European Vital Control (EVC) + GNSS-Based Location Determination System On-Board Unit (LDS-OBU) (owned by the Ansaldo STS)
- ✓ Telecommunication Network (EVC < == > RBC) : Public Switching and Satellite Network



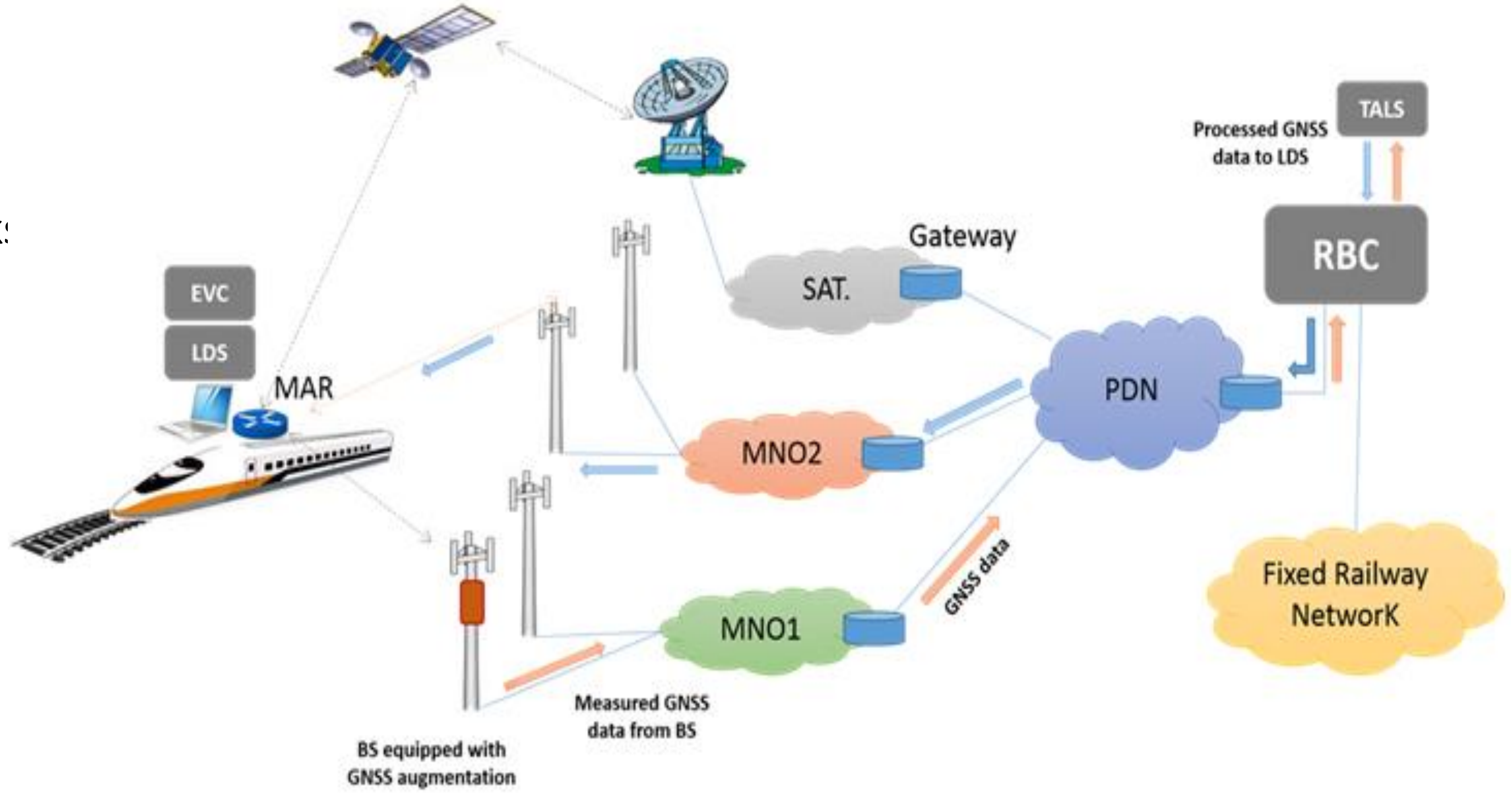
Ansaldo STS A Hitachi Group Company · Università Bocconi · ceit · DB NETZE · DLR · ESSP · RadioLabs · RFI Rete Ferroviaria Italiana · sogei · Telespazio · Trenitalia

ERSAT – EAV

SARDINIA TEST BED

Radio telecommunication networks

- Public Switching (4G/GPRS)
- Satellite communication



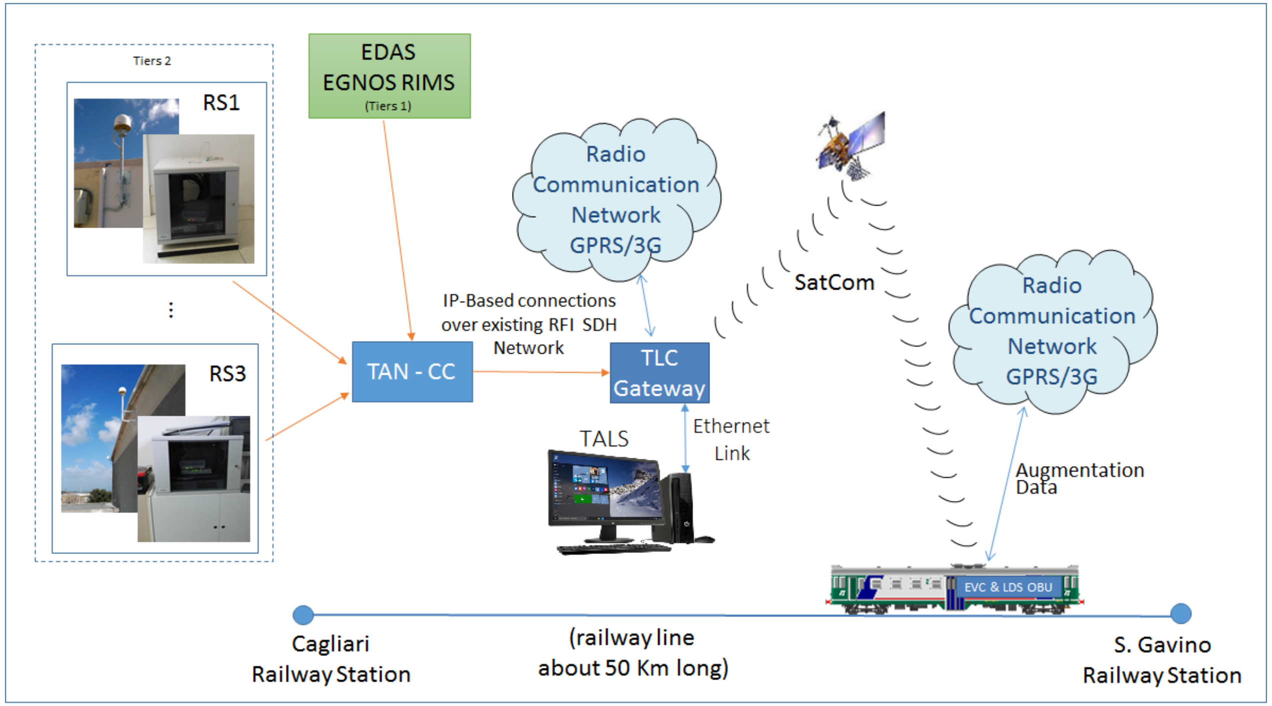
Ansaldo STS A Hitachi Group Company · Università Bocconi · ceit · DB Netze · DLR · ESSP · RadioLabs · RFI Rete Ferroviaria Italiana · sogei · Telespazio · Trenitalia

ERSAT – EAV

EXPERIMENT DESCRIPTION

The experiment only used some subsystem

- ✓ ROUTE
  - Cagliari – San Gavino Monreale
- ✓ 1st Tier:
  - EGNOS
- ✓ 2nd Tier:
  - Public Local Area Augmentation Network (owned by the SOGEI)
- ✓ TALS (Track Area LDS Server) by RADIOLABS
- ✓ LDS-OBU (Location Determination System-OBU) by RADIOLABS deployed on train ALN.668
- ✓ Telecommunication Network (EVC < == > RBC) : Public Switching and Satellite Network



ERSAT – EAV

Sardinia TEST SCENARIOS

Measurements campaign date: **October 2016**

Total rides: **12**

SCENARIO 1

CONSTELLATIONS USED: **GPS + GALILEO**

OPERATIONAL CONDITION: **Nominal**

SCENARIO 2

CONSTELLATION USED: **GPS + GALILEO**

OPERATIONAL CONDITION: **Fault**

FAULTS DETAILS

- The satellite faults are injected in Real-Time by TAAN.
- The faults are simulated on GPS PRN 01, PRN 03, PRN 06, PRN 07, PRN 09 and PRN 17 on the 25th of October 2016 from 5:10 pm to 5:17 pm local time

SCENARIO 3

CONSTELLATION USED: **GPS**

OPERATIONAL CONDITION: **Nominal**

ERSAT – EAV

EXPERIMENTAL RESULTS

SCENARIO 1

CONSTELLATIONS USED: **GPS + GALILEO**

OPERATIONAL CONDITION: **Nominal**

First GALILEO Fix

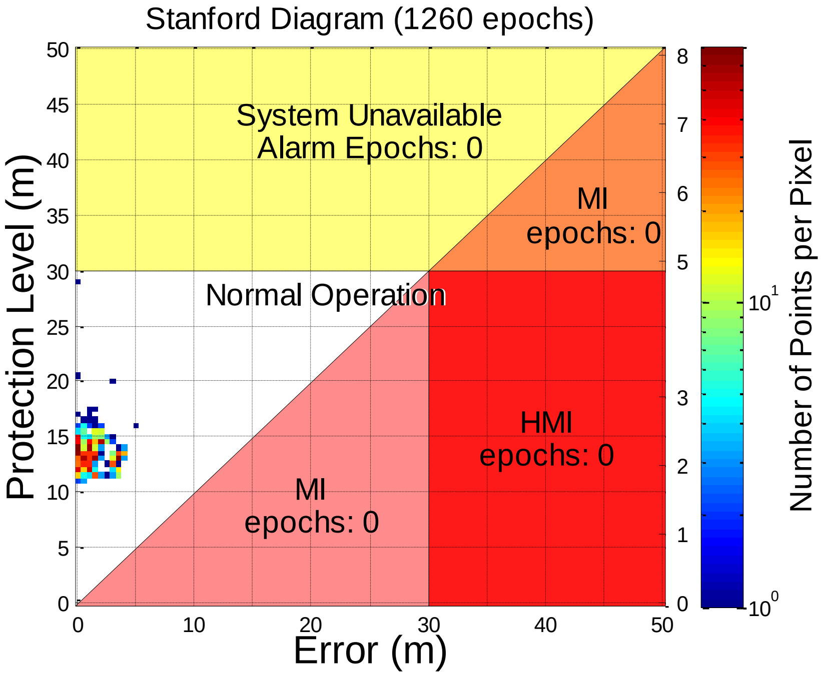


Figure 12 Stanford diagram

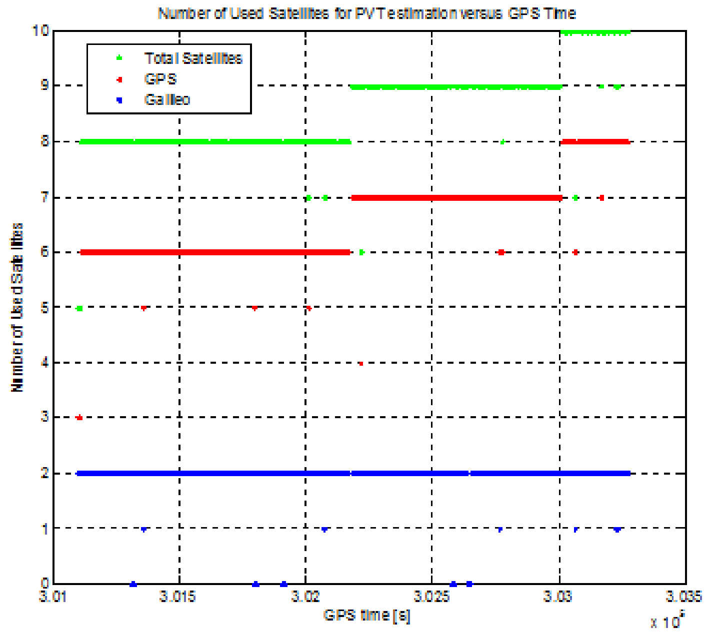


Figure 13 Number of satellites used for PVT estimation

ERSAT – EAV
EXPERIMENTAL RESULTS

SCENARIO 2

CONSTELLATIONS USED: **GPS + GALILEO**

OPERATIONAL CONDITION: **Fault**

FAULTS DETAILS

- The satellite faults are injected in Real-Time by TAAN.
- The faults are simulated on GPS PRN 01, PRN 03, PRN 06, PRN 07, PRN 09 and PRN 17 on the 25th of October 2016 from 5:10 pm to 5:17 pm local time

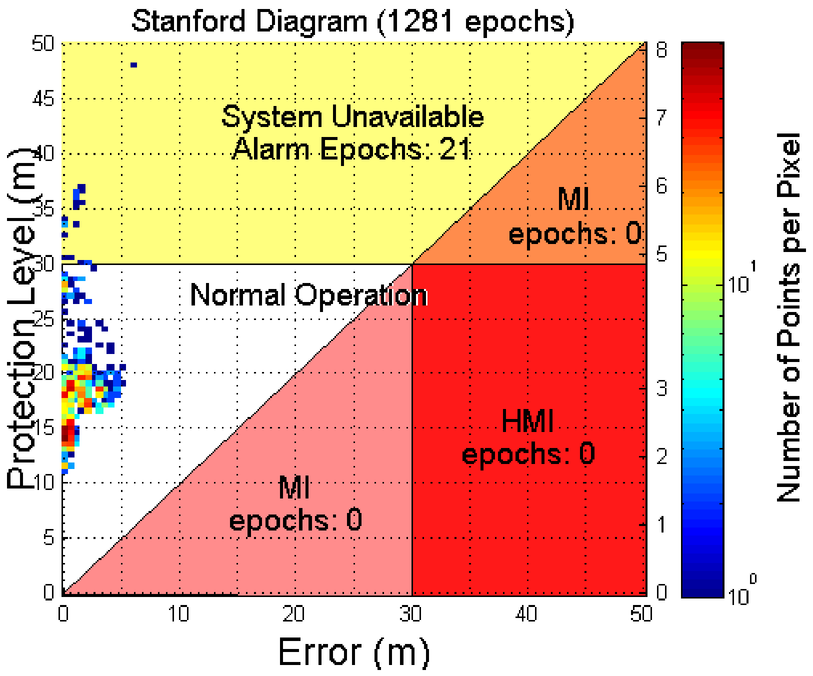


Figure 12 Stanford diagram

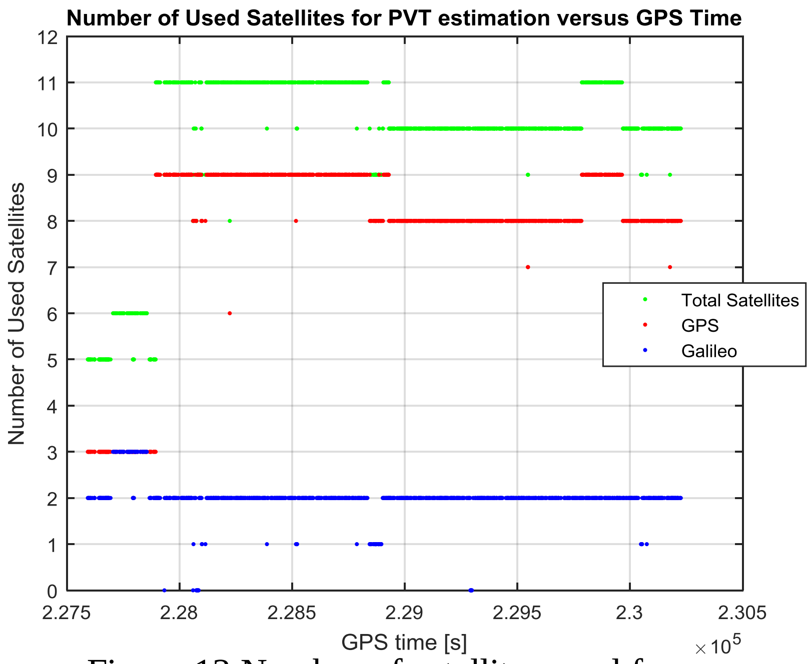


Figure 13 Number of satellites used for PVT estimation

ERSAT – EAV

EXPERIMENTAL RESULTS

SCENARIO 3

CONSTELLATIONS USED: **GPS**

OPERATIONAL CONDITION: **Nominal**

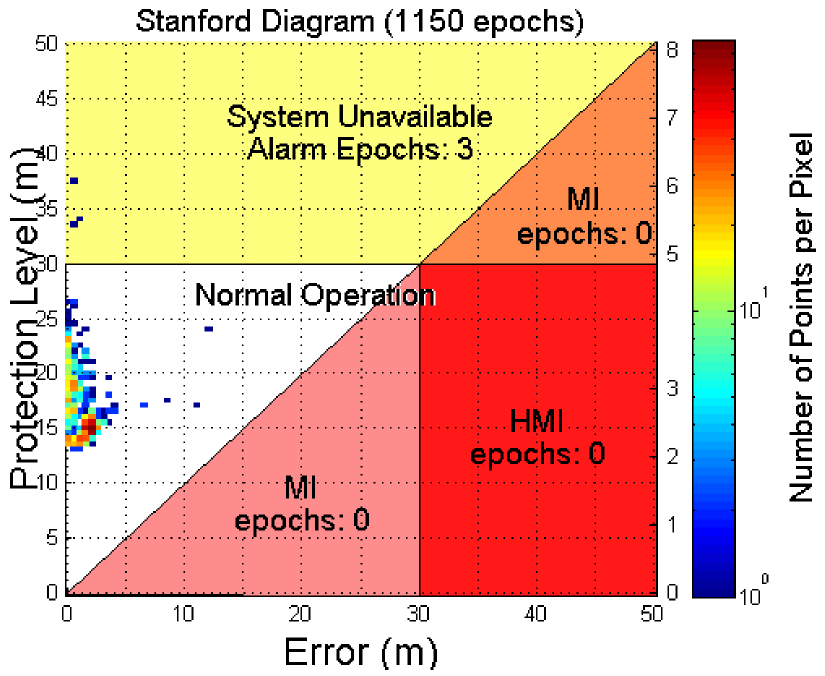


Figure 12 Stanford diagram

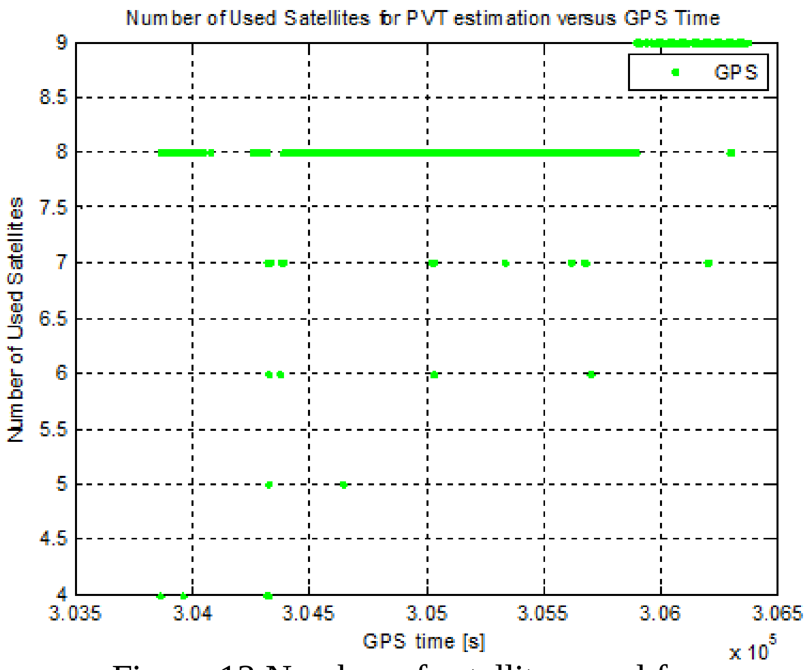


Figure 13 Number of satellites used for PVT estimation

ERSAT – EAV

CONCLUSIONS

- **Multi-layer approach** to the design and implementation of an augmentation network supporting railway applications has been verified in a real operational environment

- Additional tests will be carried out with the **Galileo constellation** entering into pre-operational service

- Results will be contributing to the **ERTMS roadmap** for adopting the GNSS


THANKS FOR YOUR ATTENTION