EGNSS MATE
Final Presentation

Speakers and Consortium

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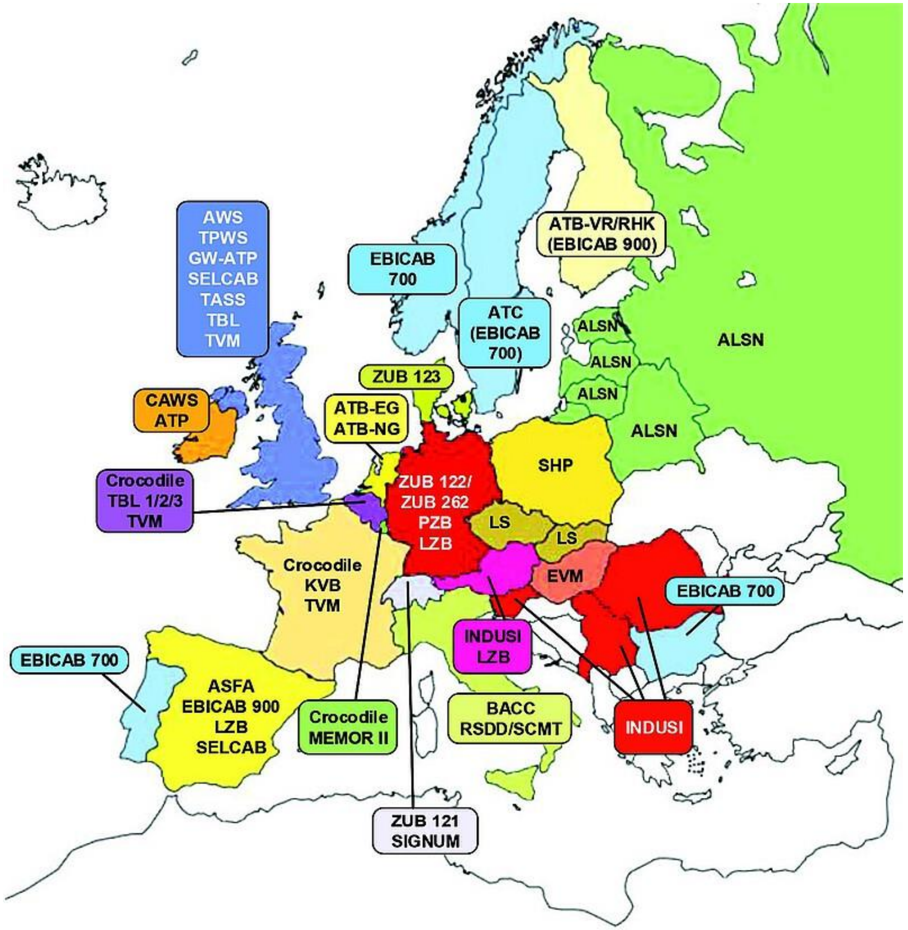
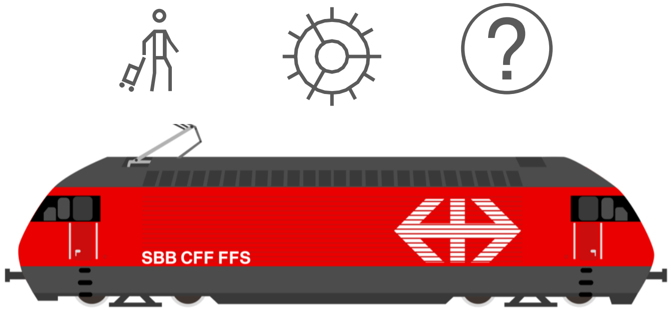
Agenda

1. Introduction and Motivation
2. Main Insights and Results
   - System Architecture
   - Algorithm Development
   - Jamming and Spoofing Tests
   - Novel Galileo Services
   - Measurement Campaign
   - Big Data Analysis
3. Conclusions and Outlook

Introduction and Motivation

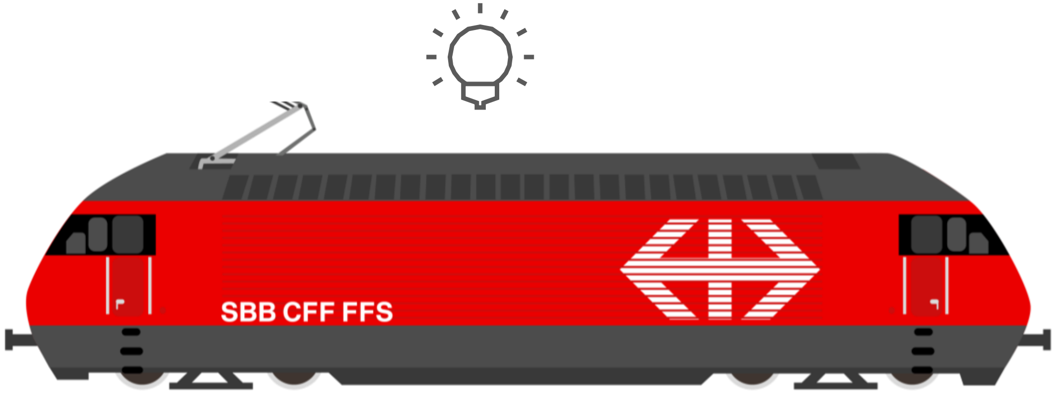
History of ERTMS





Trains needed to be equipped with a variety of train control systems to be able to run in different countries

ETCS promises ...



Easy cross-border traffic!

Higher capacity and lower costs!

No need for double equipment!

… and in reality

International Railway Journal

[Will ERTMS ever reach critical mass in Europe?]

Although the EU only agreed a revised ERTMS deployment for Europe in 2017, the timetable for implementing ETCS is suffering delays.

06.02.2020

Railway Gazette

ETCS rollout re-evaluated | News

NETHERLANDS: The national roll-out of the European Rail Traffic Management System is to be delayed pending a re-evaluation of the priorities...

18.01.2016

Front Himmel und Hölle Nahostkonflikt Ukraine #WIRSINDZUKUNFT Sport Schweiz Zürich Bern

Front | Wirtschaft | **Verspätungen bei der SBB: Neues Sycherheitssystem ETCS sorgt für Ärger**

LOKFÜHRER TOBEN

Publiziert 19. Februar 2023, 15:54

Neues europaweites Sicherheitssystem führt zu mehr Verspätungen bei der SBB

Das System kostet Hunderte Millionen Franken, verursacht aber vor allem mehr Aufwand. Die Probleme sollen laut SBB in zwei Jahren behoben sein.

New European safety system leads to more delays at SBB.

INFRASTRUKTUR & AUSRÜSTUNG

Digitaler Knoten Stuttgart: DB räumt Probleme mit ETCS ein

Auf der Strecke Wendlingen - Ulm kämpft die Deutsche Bahn mit Problemen bei ETCS. Quelle: Deutsche Bahn AG / Max Lautenschläger

Artikel
Redaktion Eurailpress

Kontakt
Teilen
Drucken

DB is admitting problems with ETCS

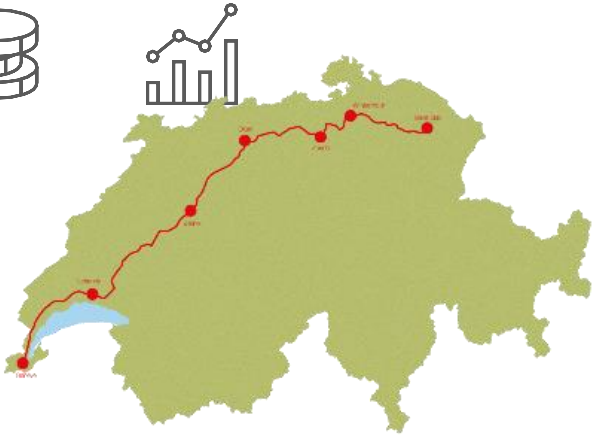
Current Problems with current ETCS

High infrastructure costs

Partially a reduction of capacity

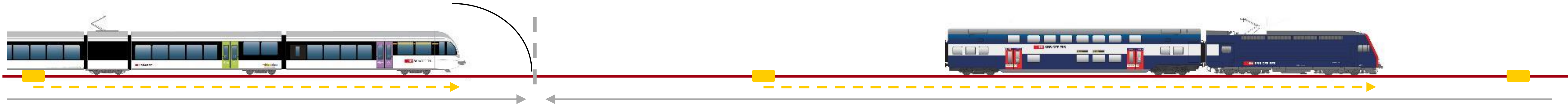
Upgrades of vehicle equipment expensive

Odometry issues lead to system failures



Our vision: Safe on-board localisation allows reduction of trackside assets

ETCS Level 2 – Fixed Block



Block-wise track occupancy detection with axle counters and track circuits

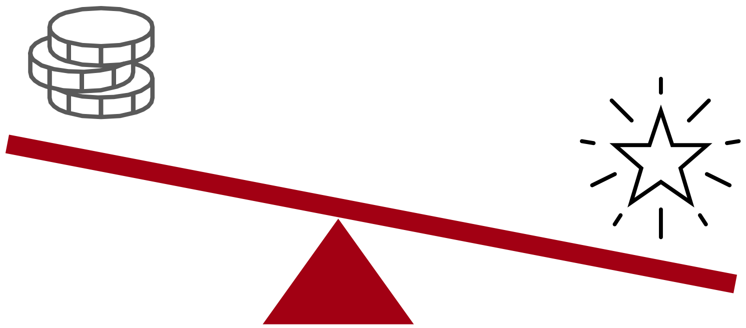
Continuous location and speed supervision using Eurobalises and odometry

ETCS Level 2 – Moving Block

Continuous track occupancy detection and speed supervision based on the max. safe front/rear end position of the train

- Transfer of liability from trackside occupancy detection to on-board localisation.
- Reduction of overall system costs, due to fewer trackside installations.
- Gain more capacity (moving permissions based on real train position vs fixed blocks).

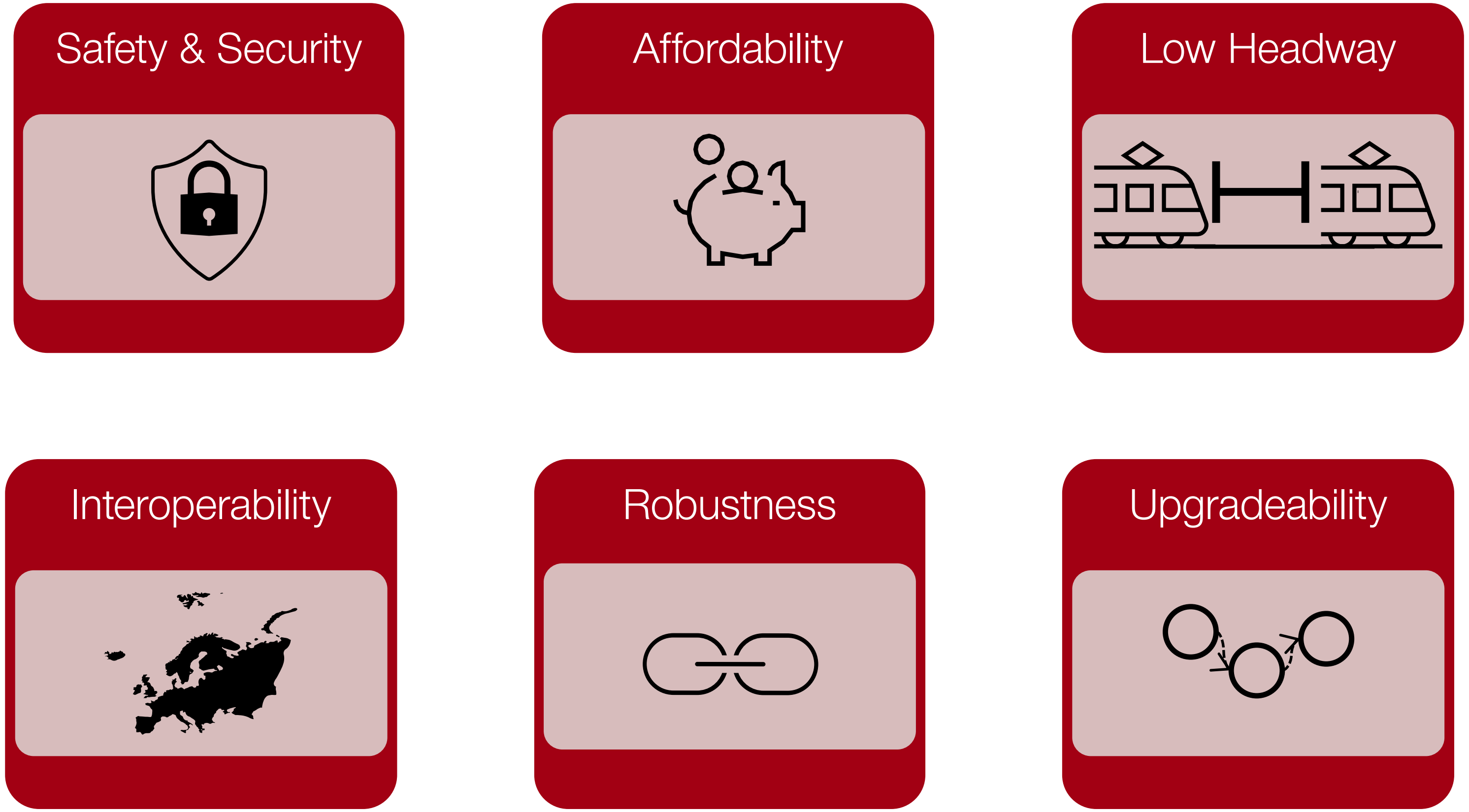
The localisation business case



Onboard train localisation	→	50% reduction of Eurobalises	→	12 k€ savings per km
+ Train Integrity	→	+ 50% reduction of trackside train detection assets	→	85 k€ savings per km

EUG Localisation Working Group Cost Benefit Analysis 2023

Localisation Requirements



The EGNSS MATE Project

Main Goals of the project:

- Development of open-source algorithms for safe train localisation with onboard GNSS, sensors and digital maps
- Collection of large test data set to validate and test the localisation algorithms
- Investigate the use of HAS and OSNMA and test for vulnerabilities for jamming and spoofing attacks

The EGNSS MATE Project

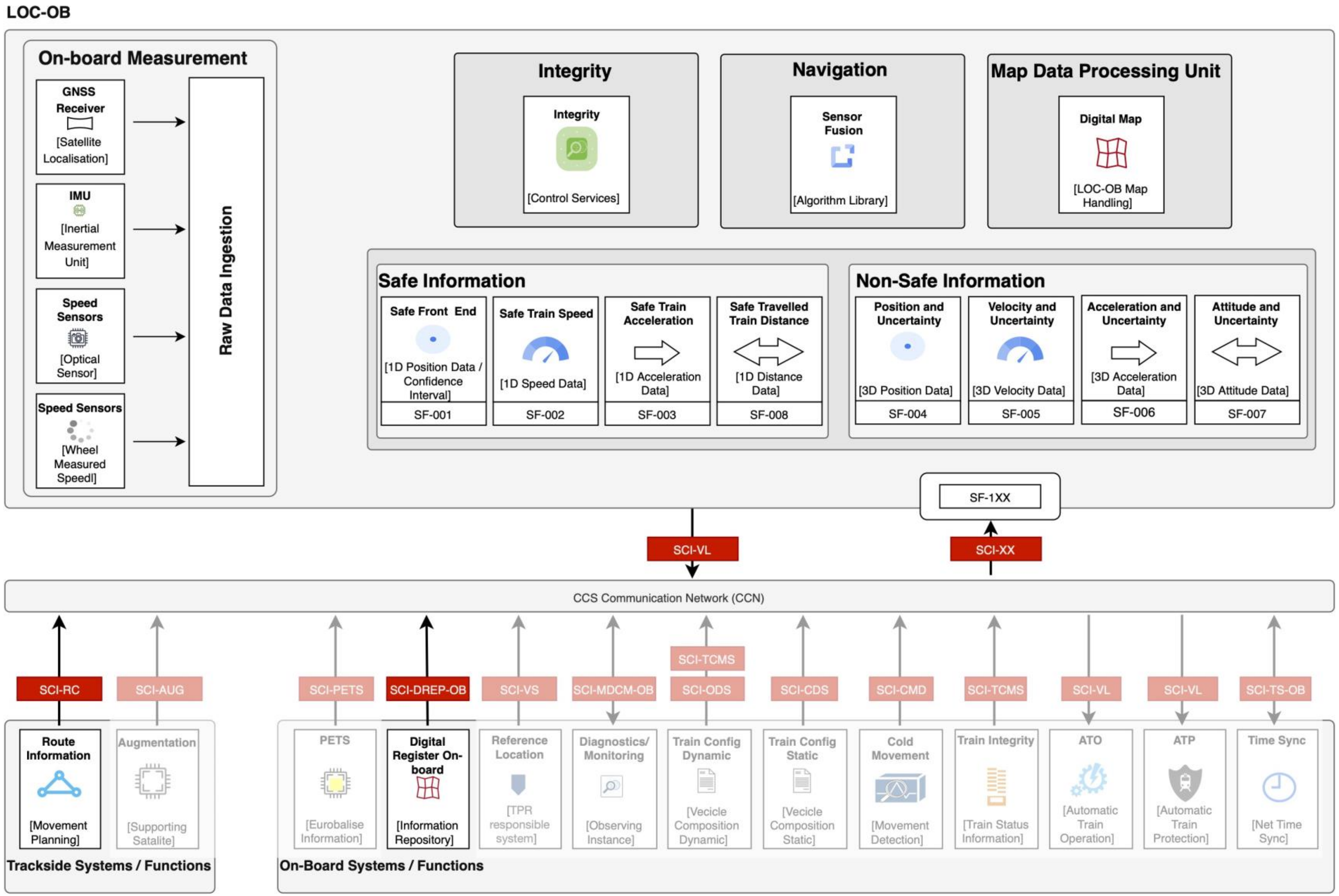
The Europe's Rail roadmap aims to introduce "Absolute Safe Train Positioning" by 2032.

EGNSS MATE supports this goal by:

- Advancing innovation and standardisation in the field of safe train localisation
- Publishing results and open-source localisation algorithms which can speed up product development and serve as a basis for standardisation activities
- Building up a testing environment for both safe and non-safe localisation solutions in rail

Main Insights and Results

Target Architecture



Algorithm Development

Algorithm development objectives

Develop and test map-supported multi sensor fusion algorithms

- Tight map data integration to exploit the track-constrained vehicle motion
- Modularity with respect to the sensor set-up and data rates
- Multiple GNSS receivers, velocity sensors, inertial measurement units
- Robust performance for GNSS outages
- Provide Python code, integrate at SBB, publish as open-source software

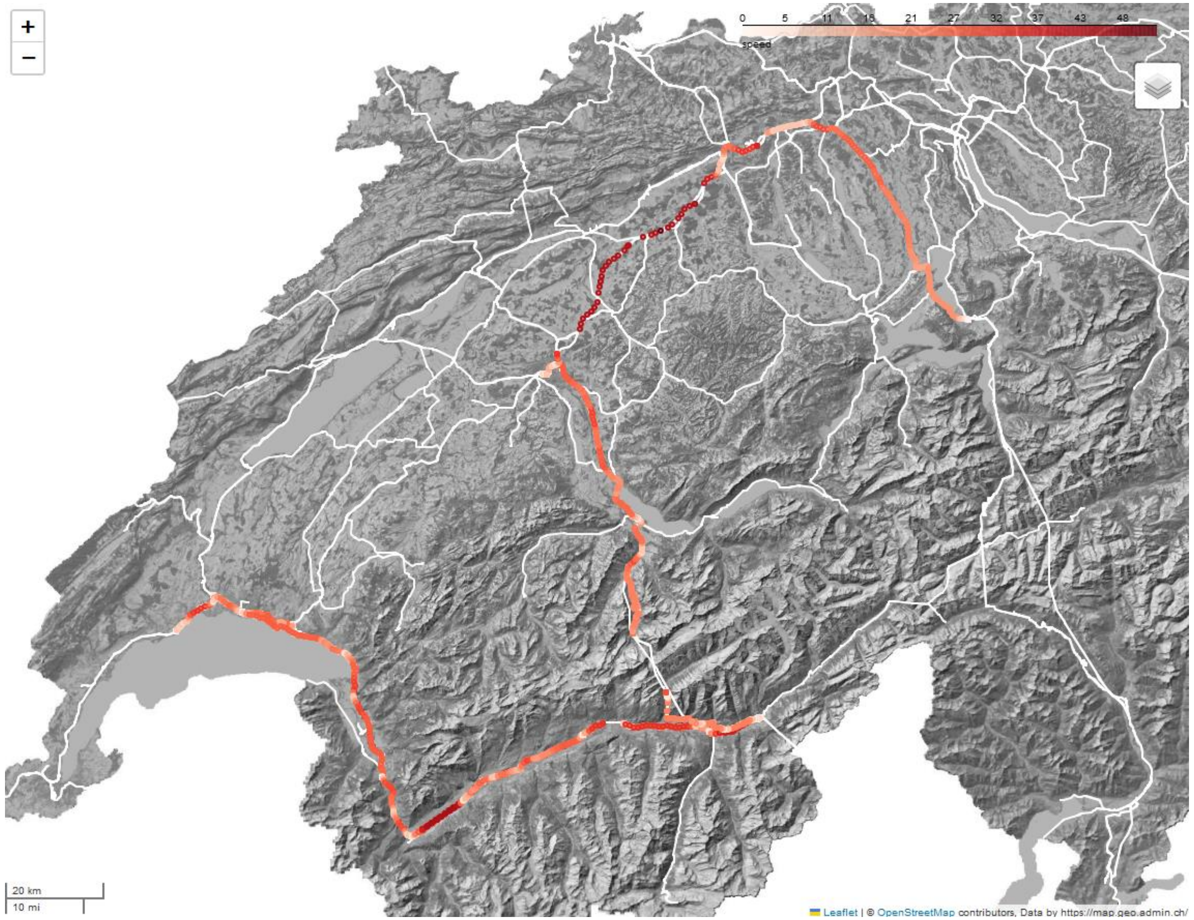
Furthermore

- Extend the state-of-the-art, follow architecture considerations, prepare suitable map data, employ domain-driven design, …

Digital maps and actual onboard sensor data

SBB map data of the entire network

- Combine geometry and topology information
- Employ timely geodata tools in Python



Actual measurement data

- November 2023 campaign and ground truth have been essential

The challenges

GNSS requires signal reception – there are inevitable outages

- Tunnels and stations, jamming and spoofing attacks

Multiple onboard sensors and systems

- GNSS, velocity sensors, inertial measurement units
- Individual rates and error characteristics
- No access to balise reader or route information granted*

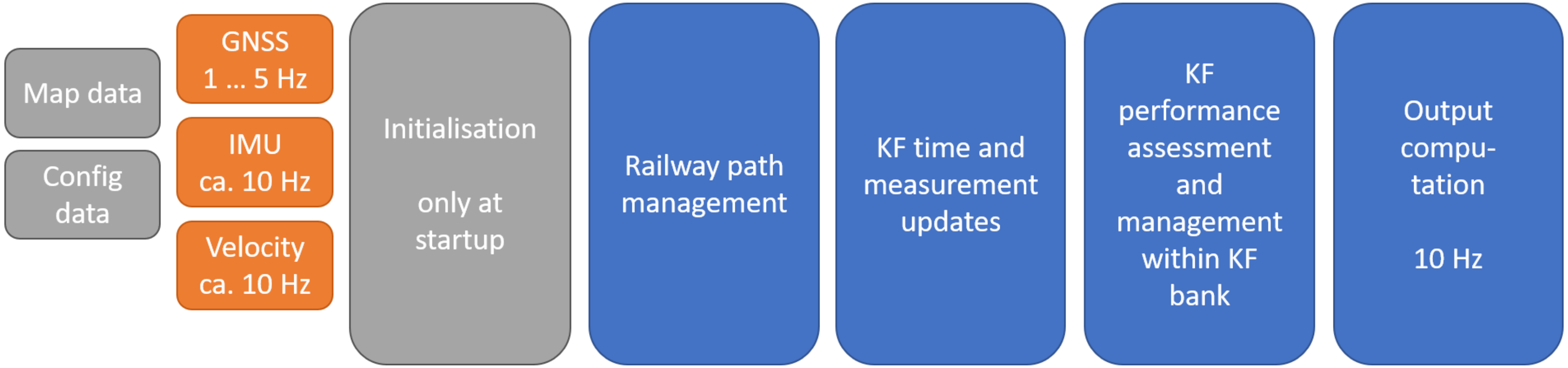
Sensor fusion algorithms

- Combine Kalman filters and tight map data integration

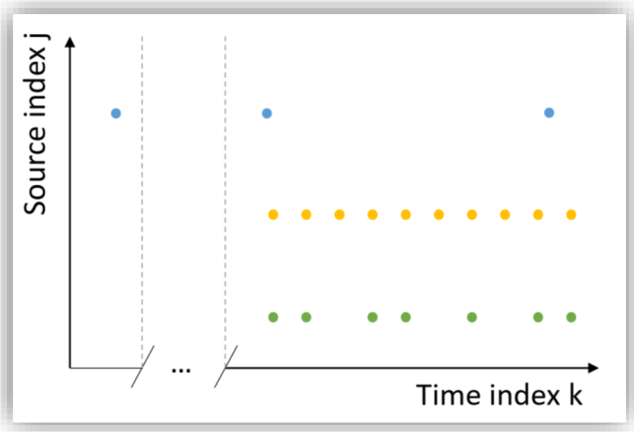
*DLR balise reader and routes used for ground truth, however

Filter bank solution

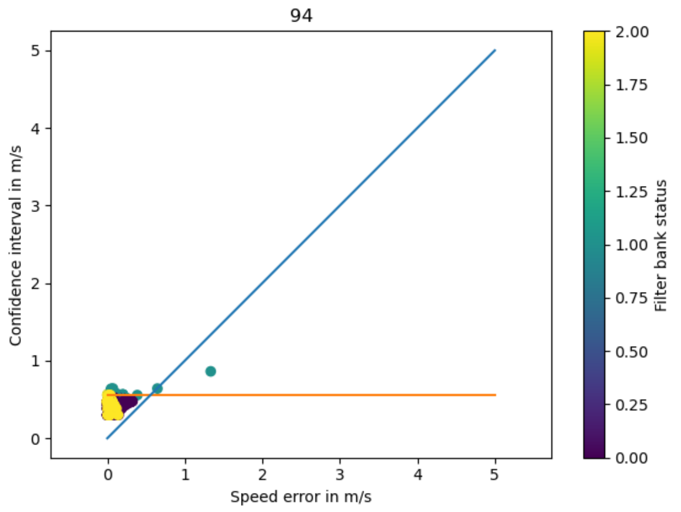
- Continuously maintain all path hypotheses underneath the vehicle
- Use one path-constrained Kalman filter (KF) per path

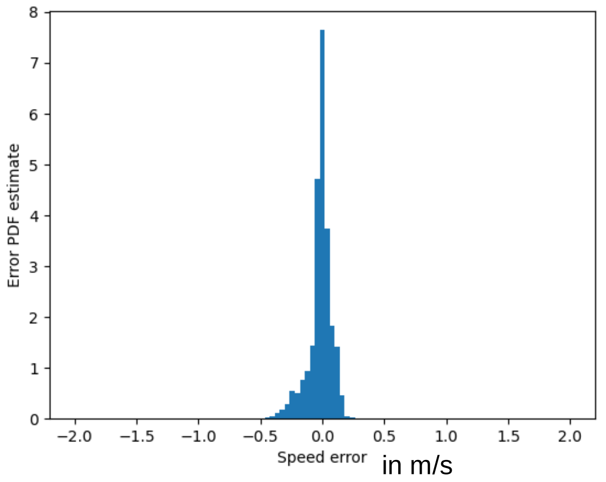


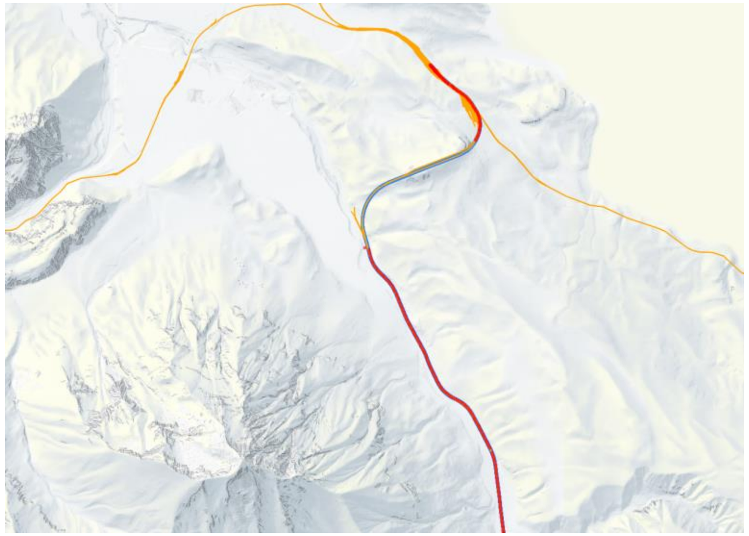
- Evaluate the average KF performance over a sliding window
- Combines KF and optimization

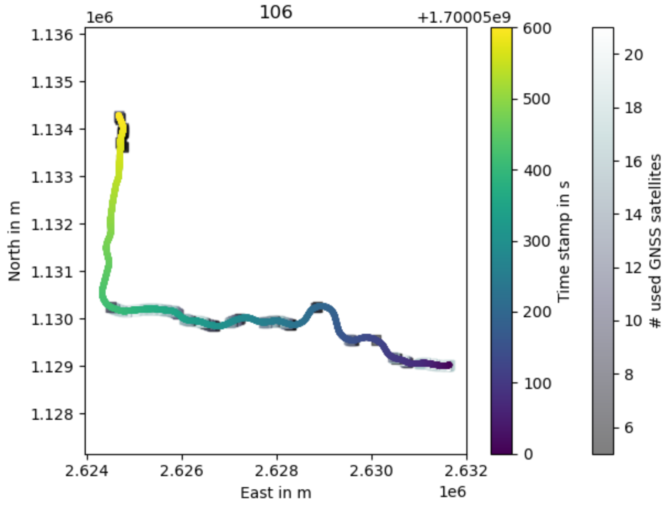


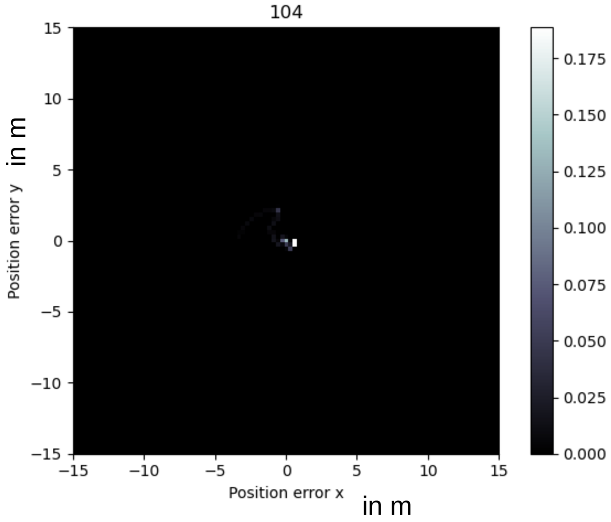
Filter bank results

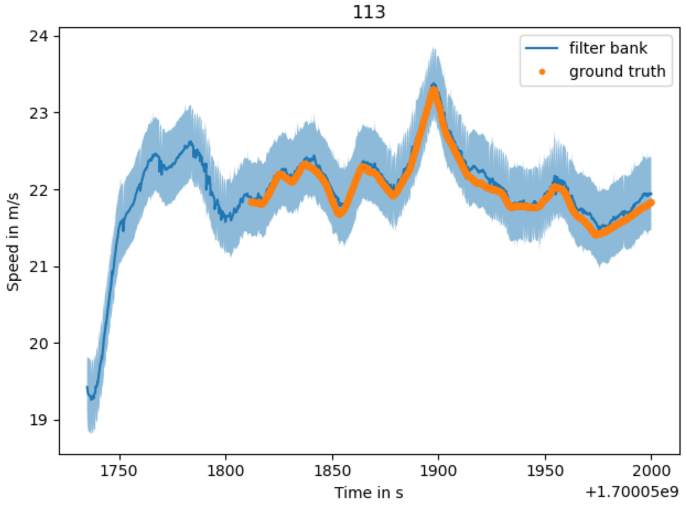












Filter bank results interactive

Algorithm development
Conclusions and outlook

- A novel filter bank approach has been developed
- Tests on challenging data were conducted with success
- Open-source software (https://github.com/DLR-TS) will increase impact
- Technical publications describe the work
- The work is relevant beyond EGNSS MATE to many stakeholders
- The work at DLR will continue – industry opportunities await

TRA TRANSPORT RESEARCH ARENA DUBLIN 2024 10th CONFERENCE • 15-18 April

EGNSS MATE: Towards accurate and reliable GNSS- and map-supported train localisation

M. Roth[1], J. Heusel[1], A. Wenz[2], S. Ohrendorf-Weiss[2], P. Mendes[3], A. Martin[3], N. Dütsch[3], and S. Baumann[3]
[1] German Aerospace Center (DLR) [2] Swiss Federal Railways (SBB) [3] Industrianlagen-Betriebsgesellschaft mbH (IABG)

On-board-Fahrzeugortung mit GNSS und digitalen Karten im Projekt EGNSS MATE

On-board vehicle localisation with GNSS and map data in the EGNSS MATE project

SIGNAL+DRAHT SIGNALLING & DATACOMMUNICATION

Michael Roth | Judith Heusel | Keivan Kiyanfar | Sebastian Ohrendorf-Weiss | Andreas Wenz | Paulo Mendes | Nikolas Dütsch | Alice Martin

Jamming and Spoofing Tests

J/S Testing objective

The evolution of the ETCS/ERTMS level 2 foresees the use of PNT GNSS-based systems to support several railway operations.

Advantages in using GNSS-based systems would include:

- Responsibility shift from track-side to on-board side
- Improve usage capacity of existing infrastructures by using the train length and not the block lengths
- Reduce cost

PNT GNSS-based systems are susceptible to several types of errors.

In the EGNSS MATE we have focused only on J/S events.

Assess the GNSS principles and impact of J/S events in the railway context, and potential propagation at the algorithm level during data fusion.

Jamming / Spoofing Test Setup: Test Cases

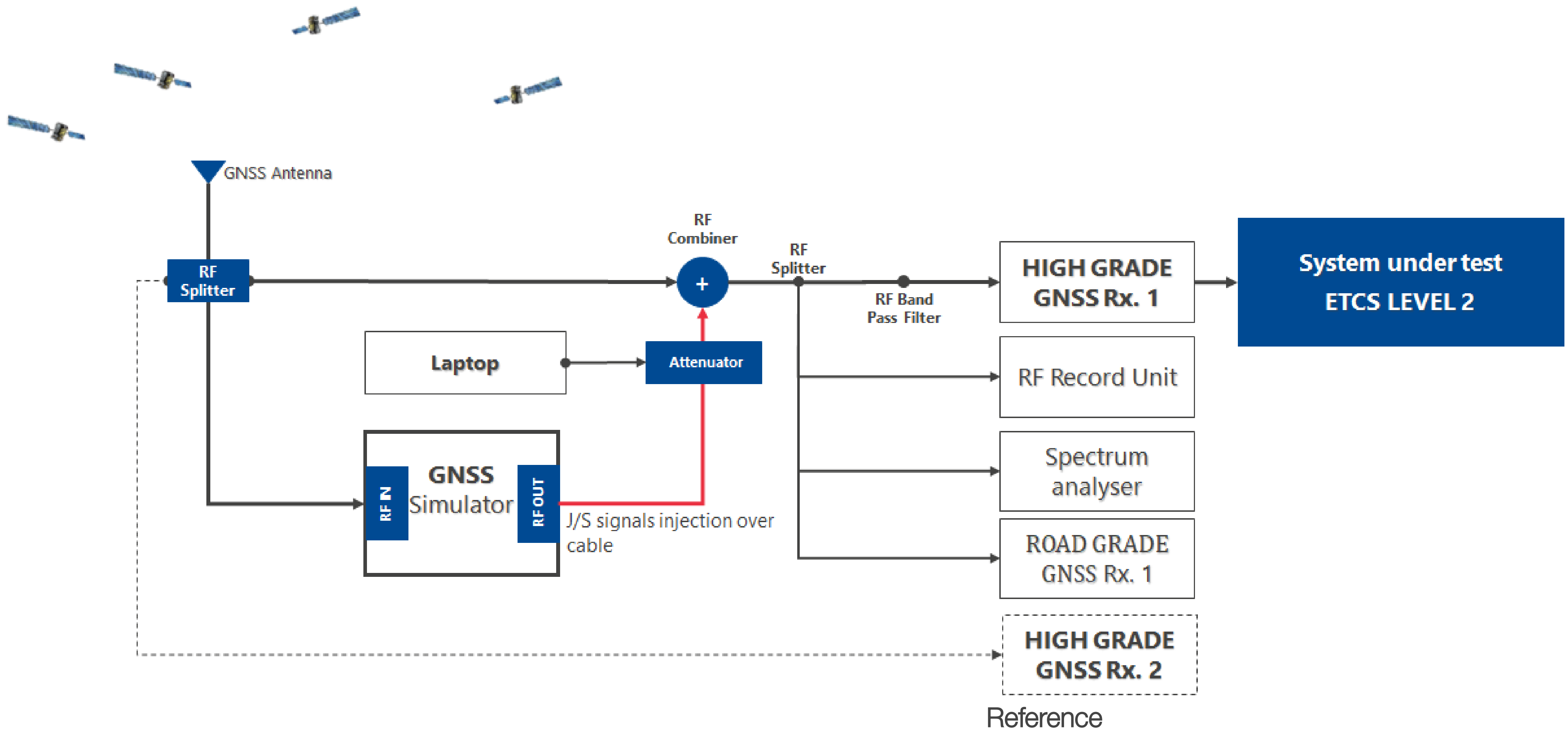
Definition of seven test cases:

- Four jamming test cases (saw-tooth chirp and matched modulation)
- Two spoofing test cases (shunting and coupling/splitting)
- One R&R case

Objective to investigate the impact on PVT at receiver level in terms of availability and accuracy. The use of the PVT solution propagates into the data fusion algorithm.

Tests were conducted over cable as no permission to broadcast signals was obtained at regulatory/legal level.

Jamming / Spoofing Test Setup

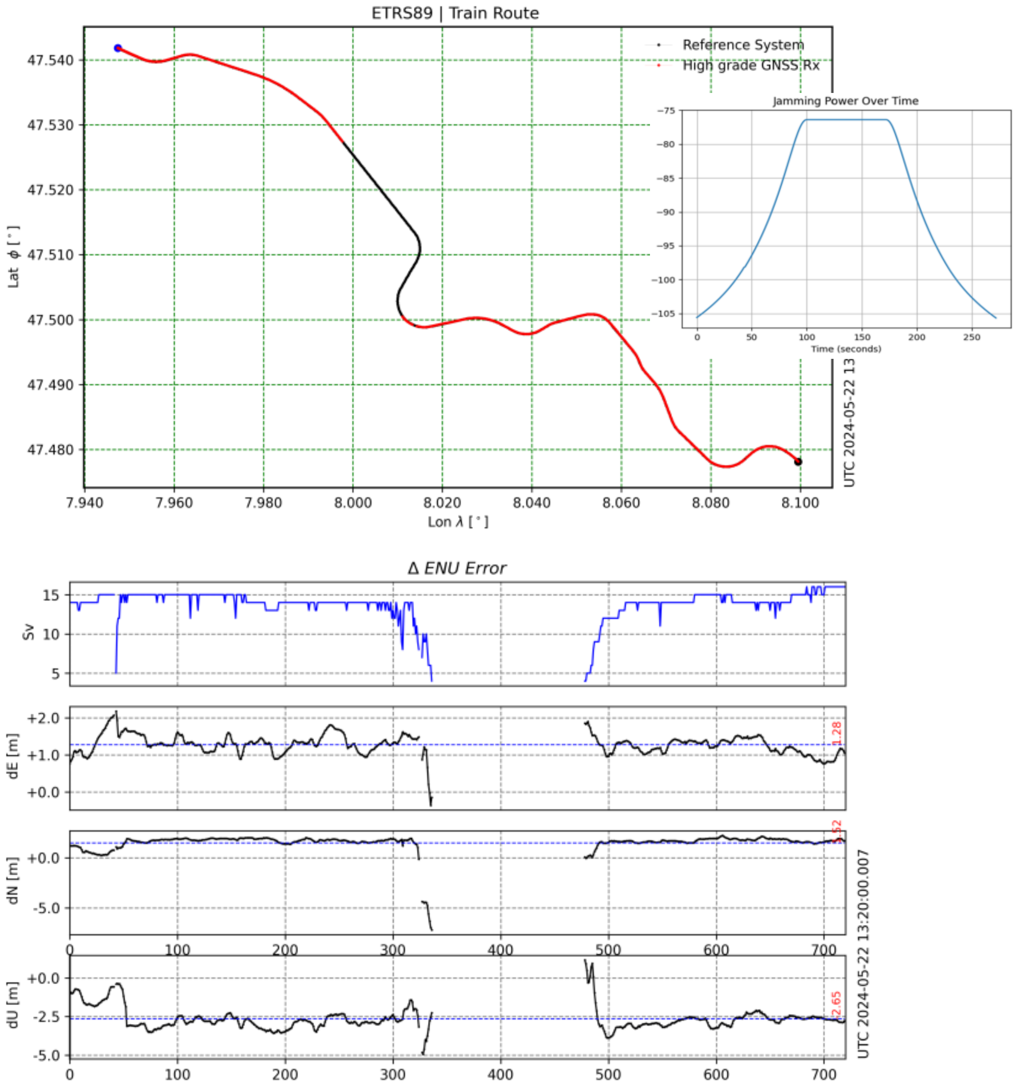


Test architecture used during the campaign performed in May 2024

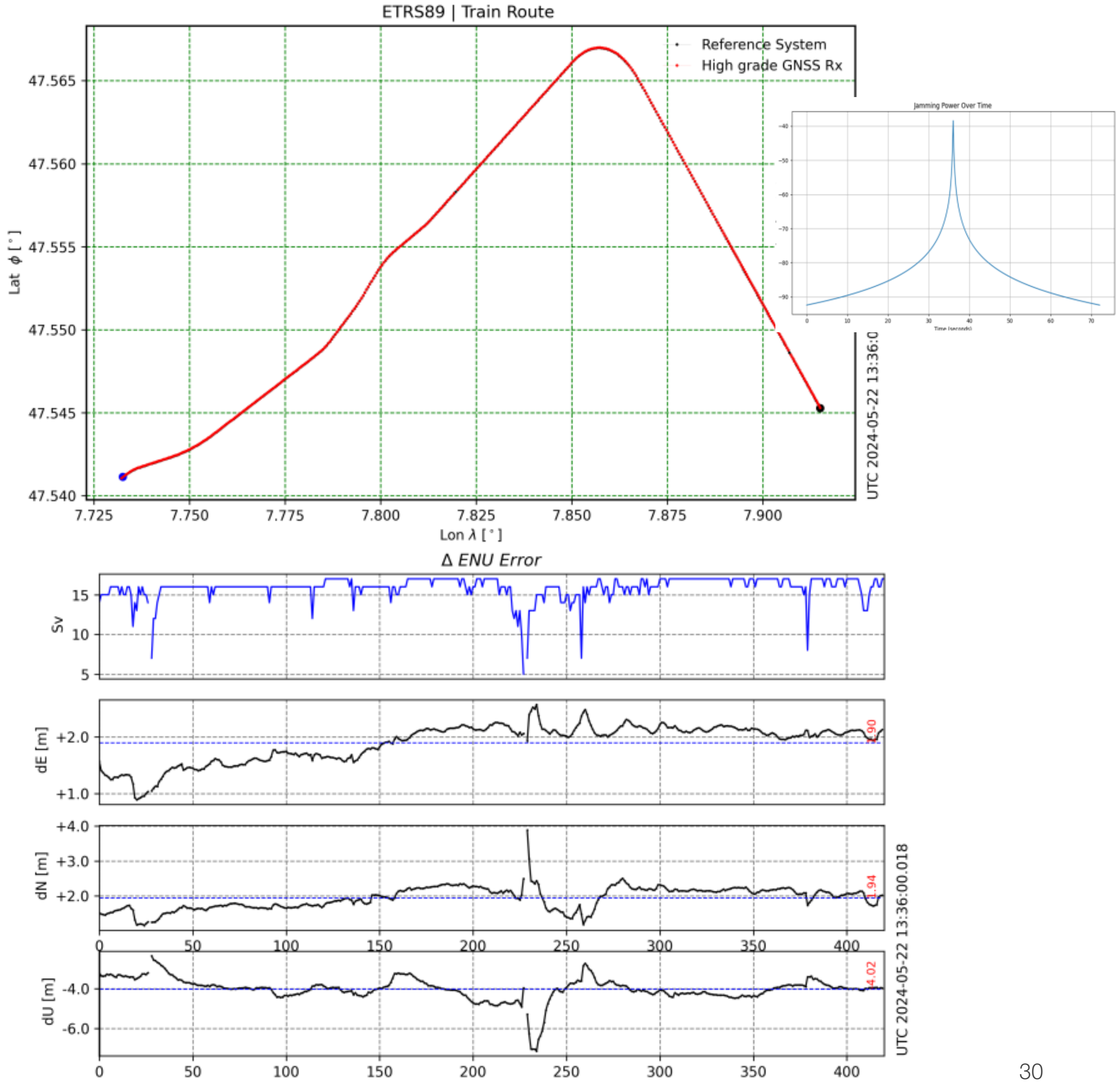
Jamming cases 1 & 2 Results

Intentional RF

Approaching, maintaining and receding from a vehicle w\ a **J**.



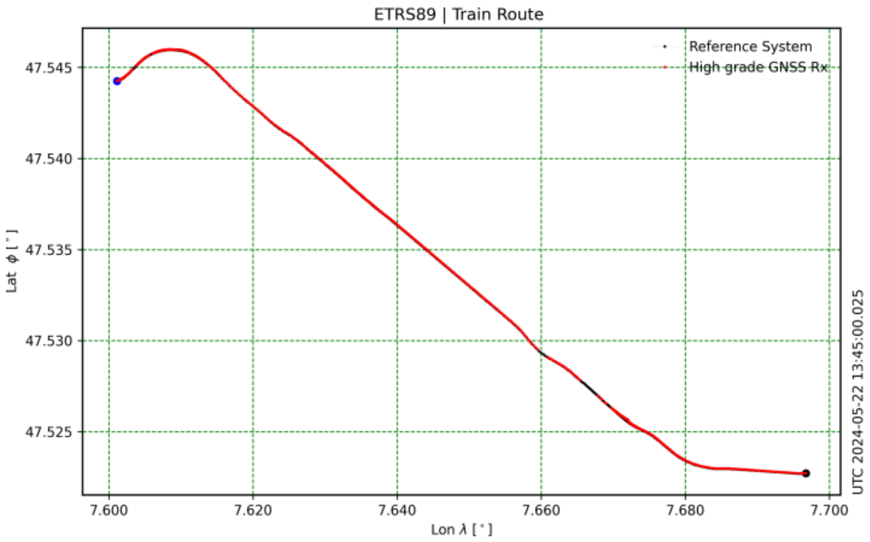
Approaching and receding from a **J** located along the train route.

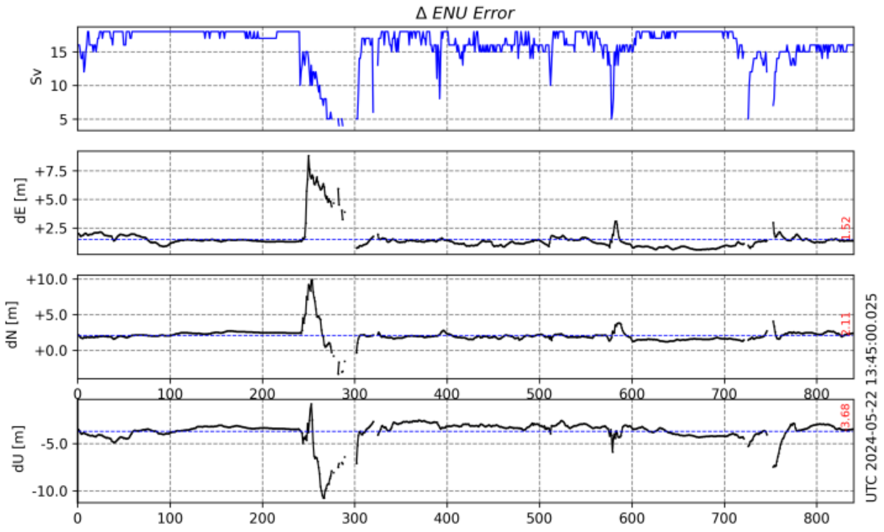


Jamming cases 3 & 4 Results

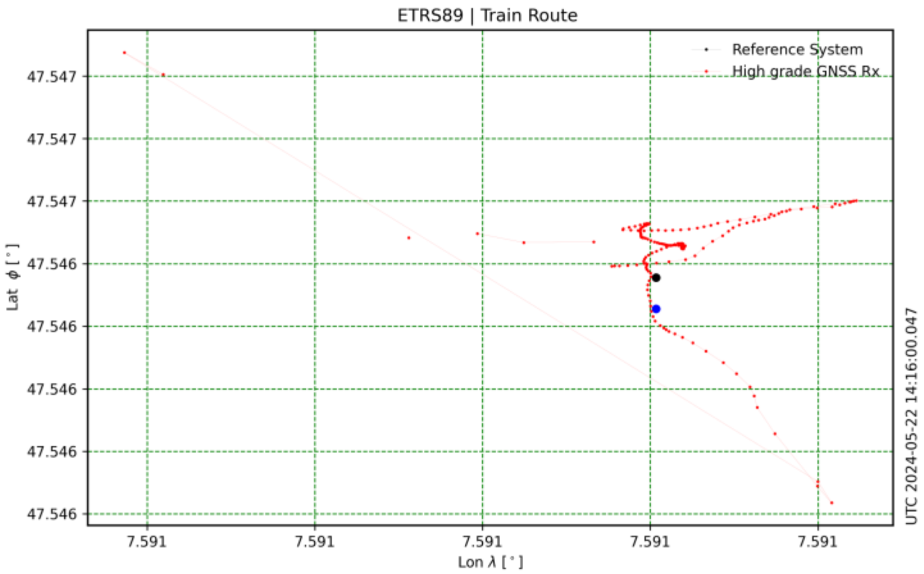
Intentional RF

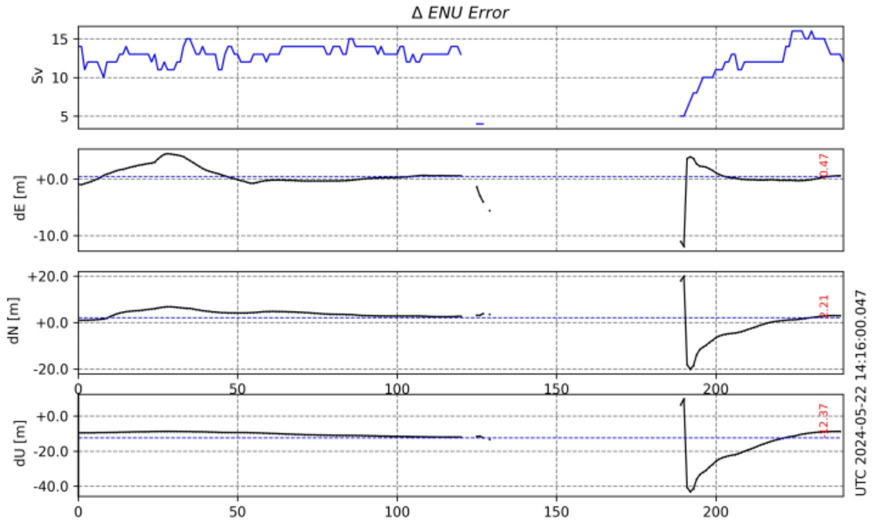
A **J** located within the train when travelling.



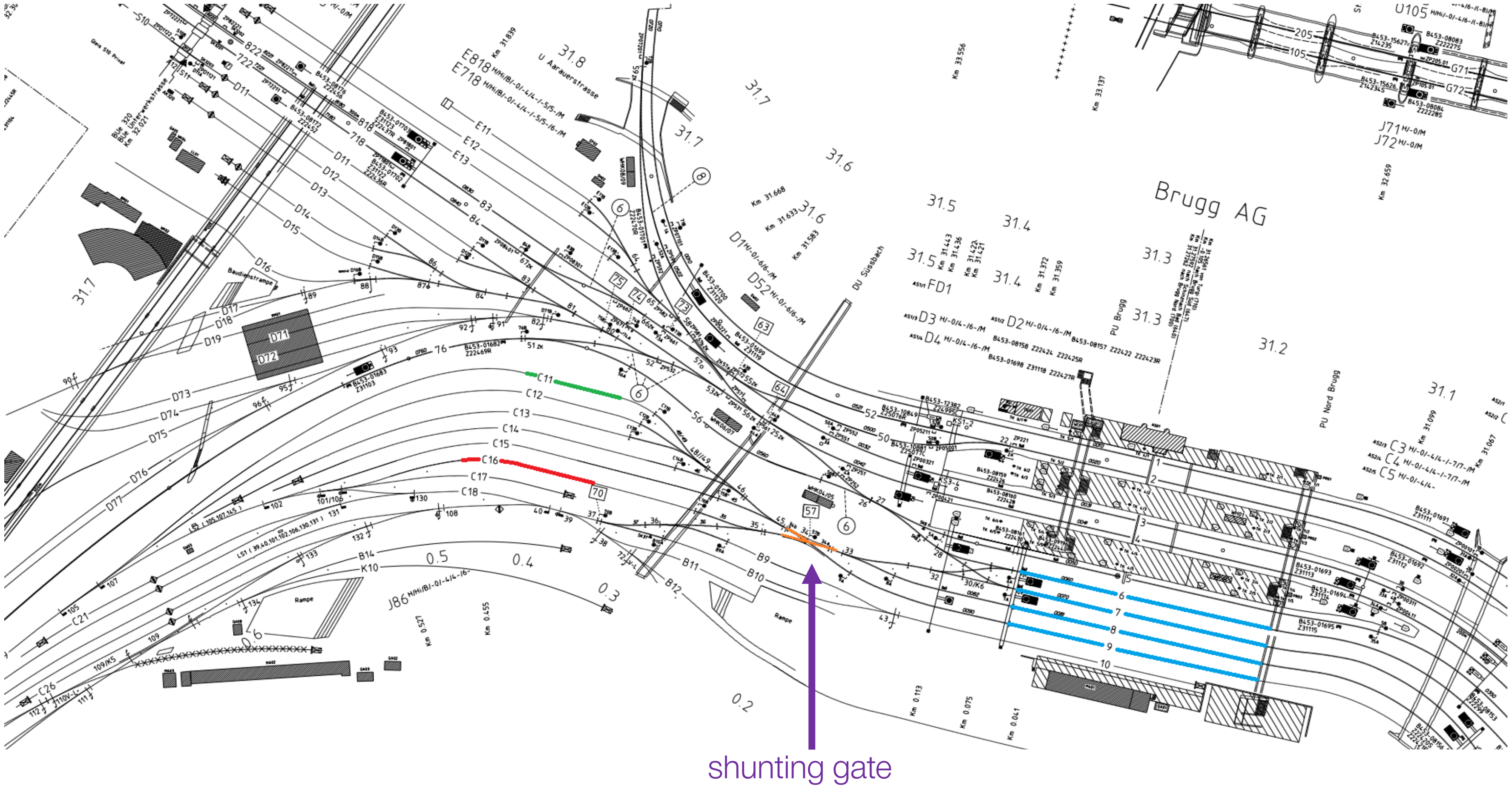


J located at the train location when parked.





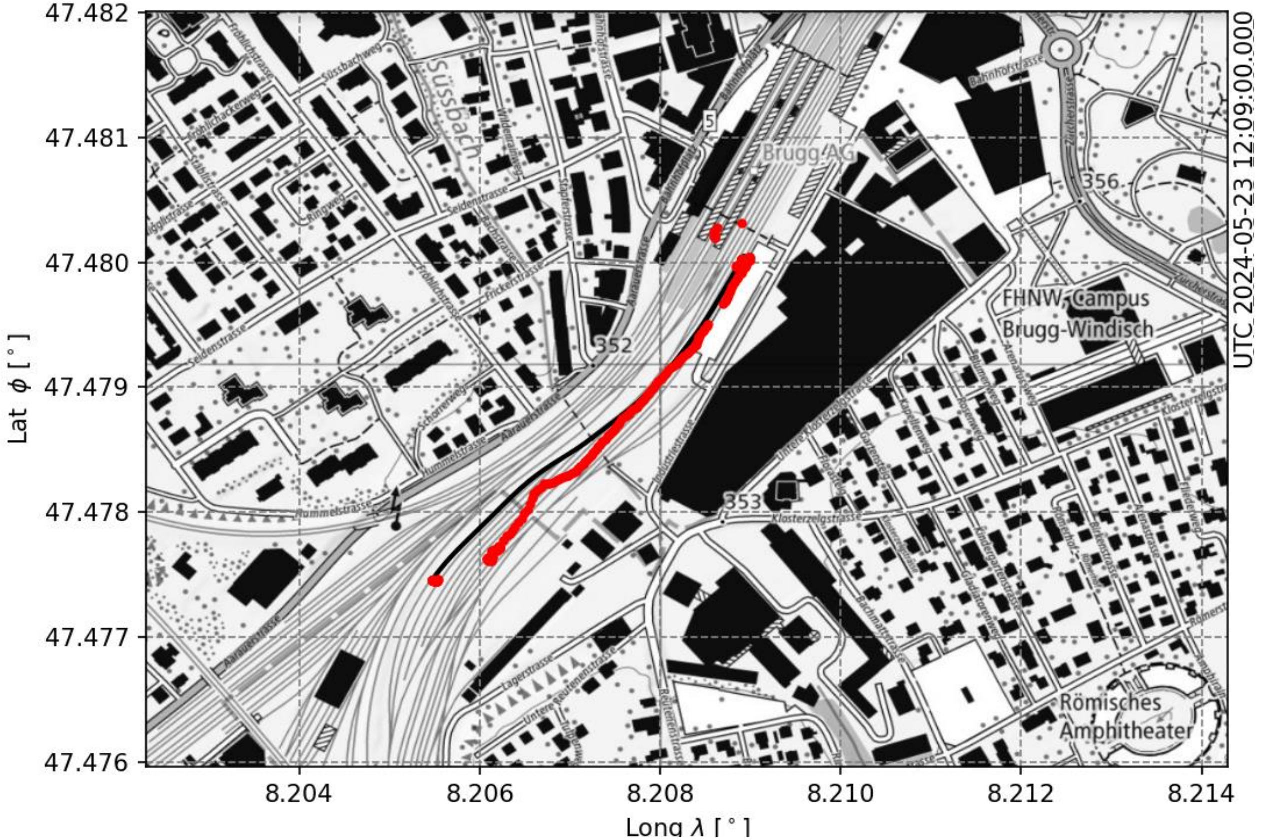
Spoofing Track Layout

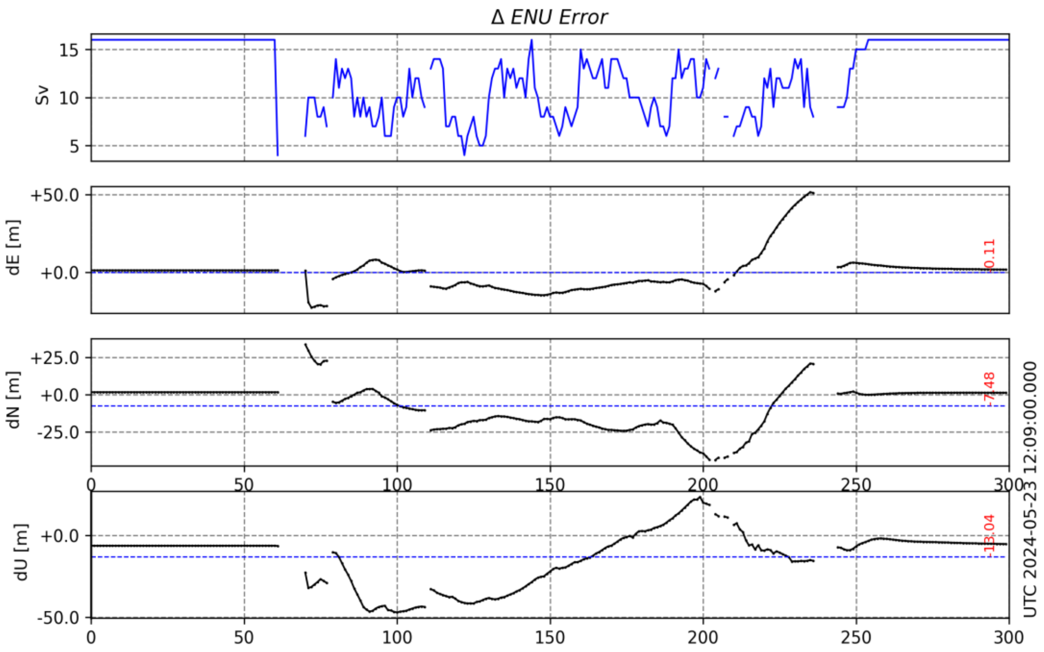


Start on one of the blue tracks and move to the green track, the system is spoofed on the red track.

Spoofing Results

Intentional RF





Map from swisstopo.

Case 5A at a shunting gate.

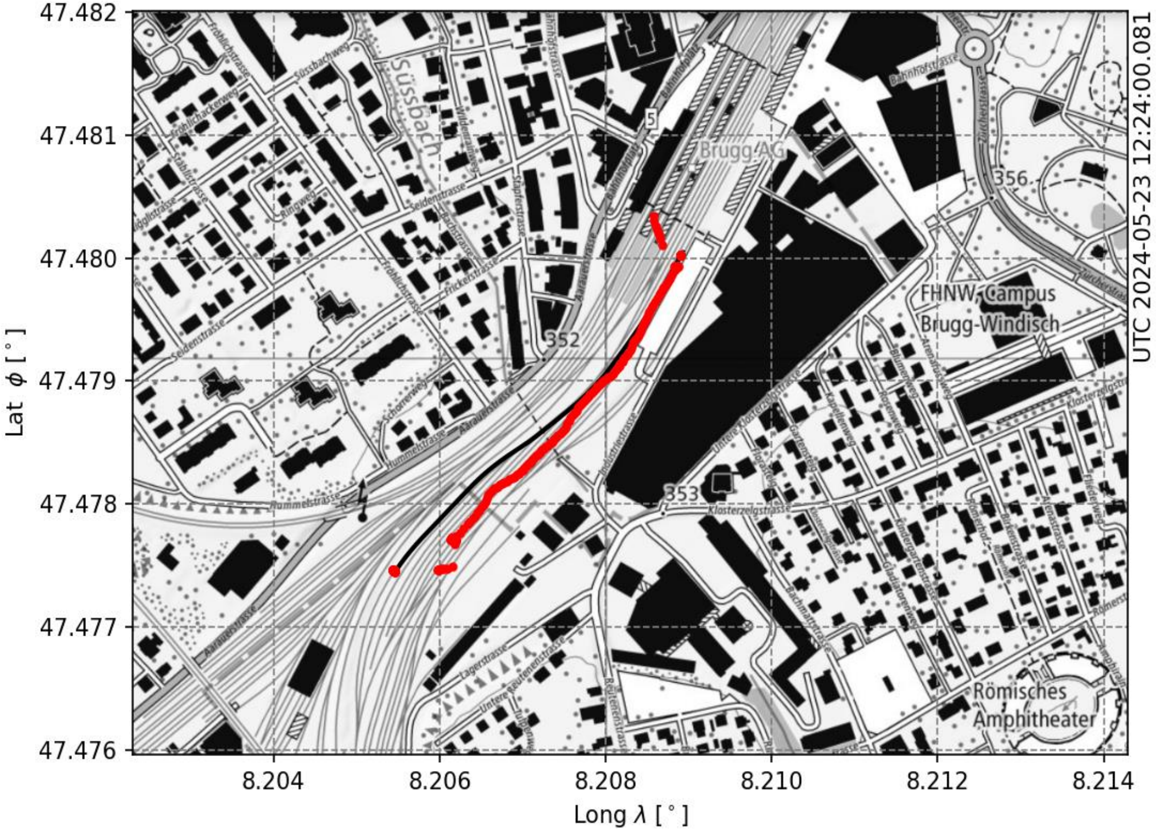
Successful Spoofing demonstrated (L1 only):

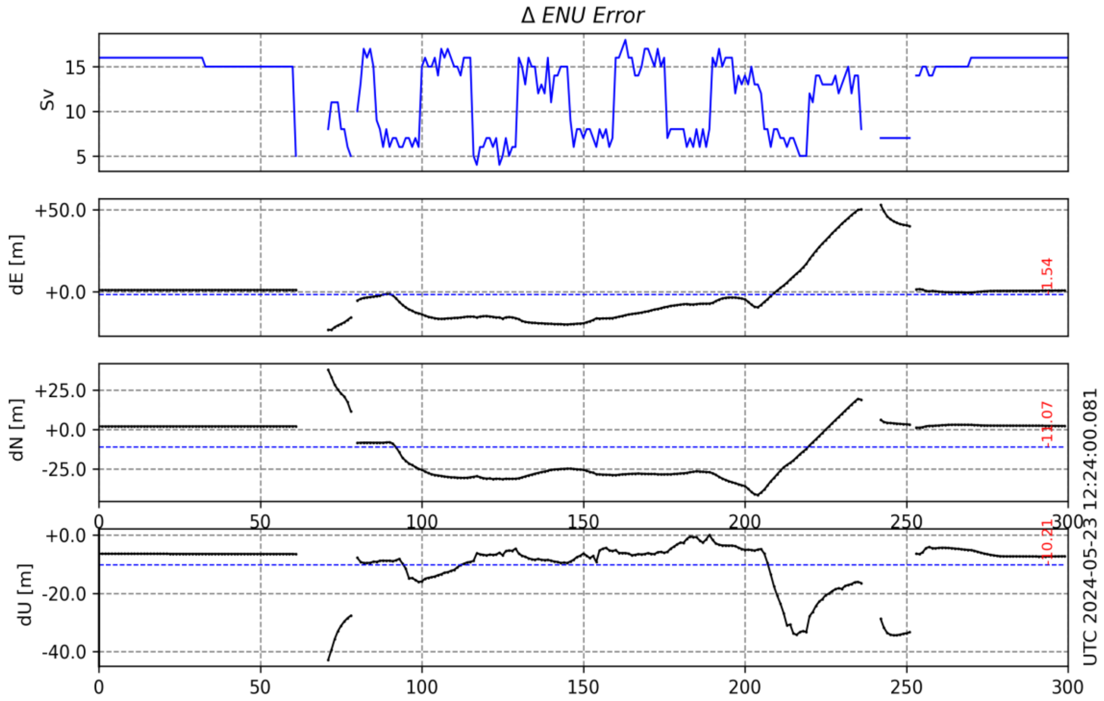
Black data points represents real train data

Red data points are determined by the GNSS RX

Spoofing Results

intentional RF





Map from swisstopo.

Case 5B at a shunting gate.

Successful Spoofing demonstrated (L1 only):

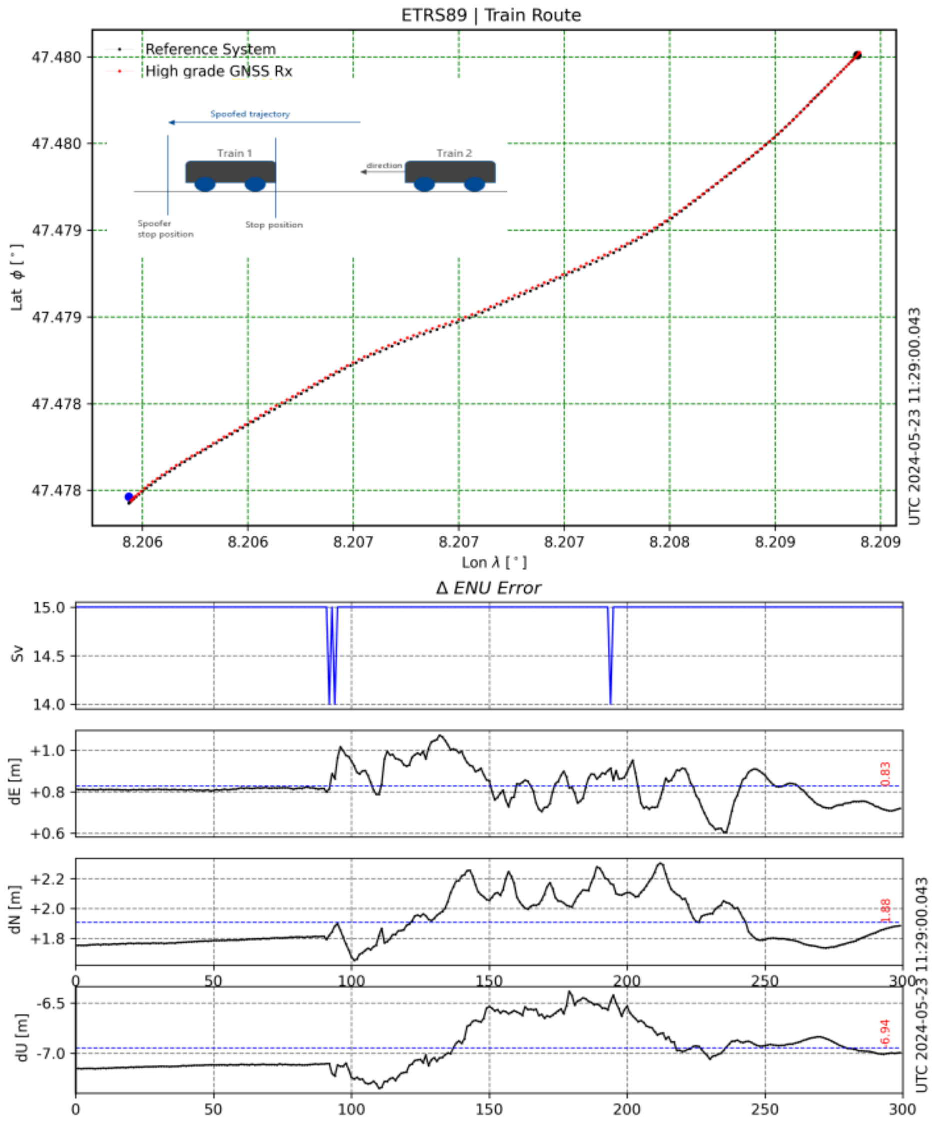
Black data points represents real train data

Red data points are determined by the GNSS RX

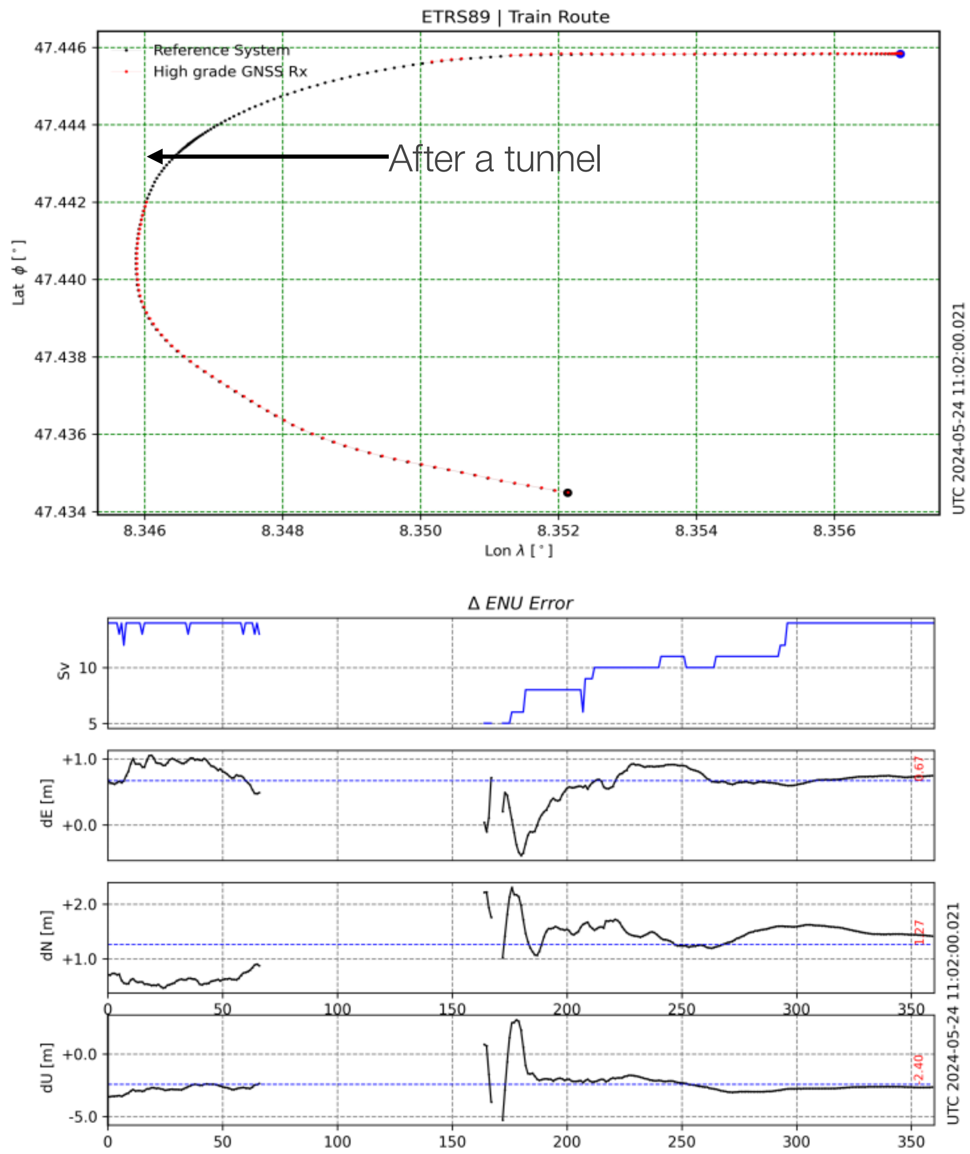
Spoofing & RR Results

Intentional RF

Spoofing attack at a coupling/splitting



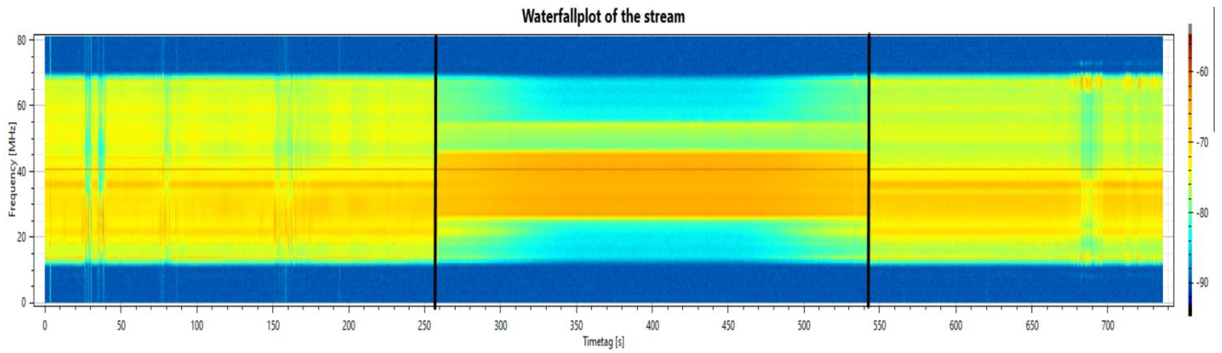
RR attack at operation startup after a tunnel.



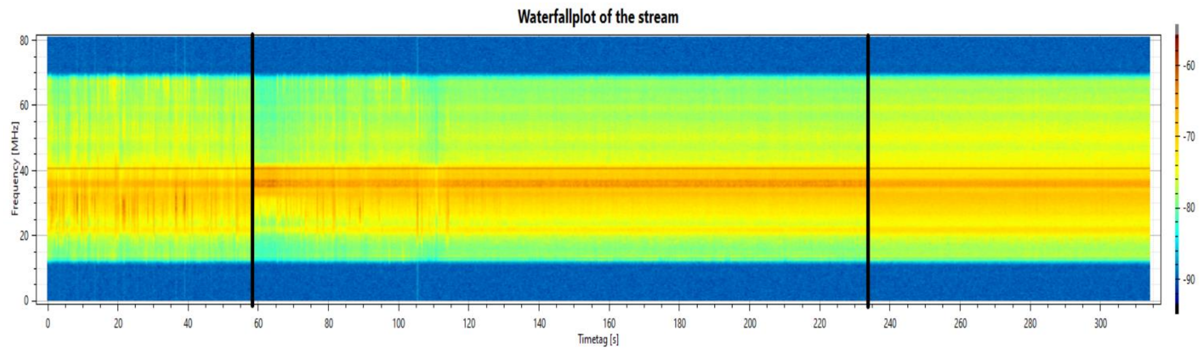
Main Results

Reference versus operational receiver results under interference conditions.

DATE	UTC TIME	TEST TYPE	TEST CASE ID	e_E [m]	e_N [m]	e_U [m]	$\lvert E_{95}\rvert$ [m]	$\lvert N_{95}\rvert$ [m]	$\lvert U_{95}\rvert$ [m]
2024/05/22	13:20:00	J	T-4000-01	+1.28	+1.52	-2.65	+1.69	+2.02	+3.47
2024/05/22	13:36:00	J	T-4000-02	+1.90	+1.94	-4.02	+2.25	+2.33	+4.77
2024/05/22	13:45:00	J	T-4000-03	+1.52	+2.11	-3.68	+2.19	+2.72	+4.93
2024/05/22	14:16:00	J	T-4000-04	+0.47	+2.21	-12.37	+4.04	+8.83	+26.27
2024/05/23	12:09:00	S	T-4000-05 (A)	-0.11	-7.48	-13.04	+23.51	+34.91	+43.66
2024/05/23	12:24:00	S	T-4000-05 (B)	-1.54	-11.07	-10.22	+40.88	+32.85	+33.22
2024/05/23	11:29:00	S	T-4000-06	+0.83	+1.88	-6.94	+0.99	+2.27	+7.24
2024/05/24	11:02:00	*R&R*	T-4000-07	+0.67	+1.27	-2.40	+0.98	+1.70	+3.04



Spectrogram associated to test case 1.

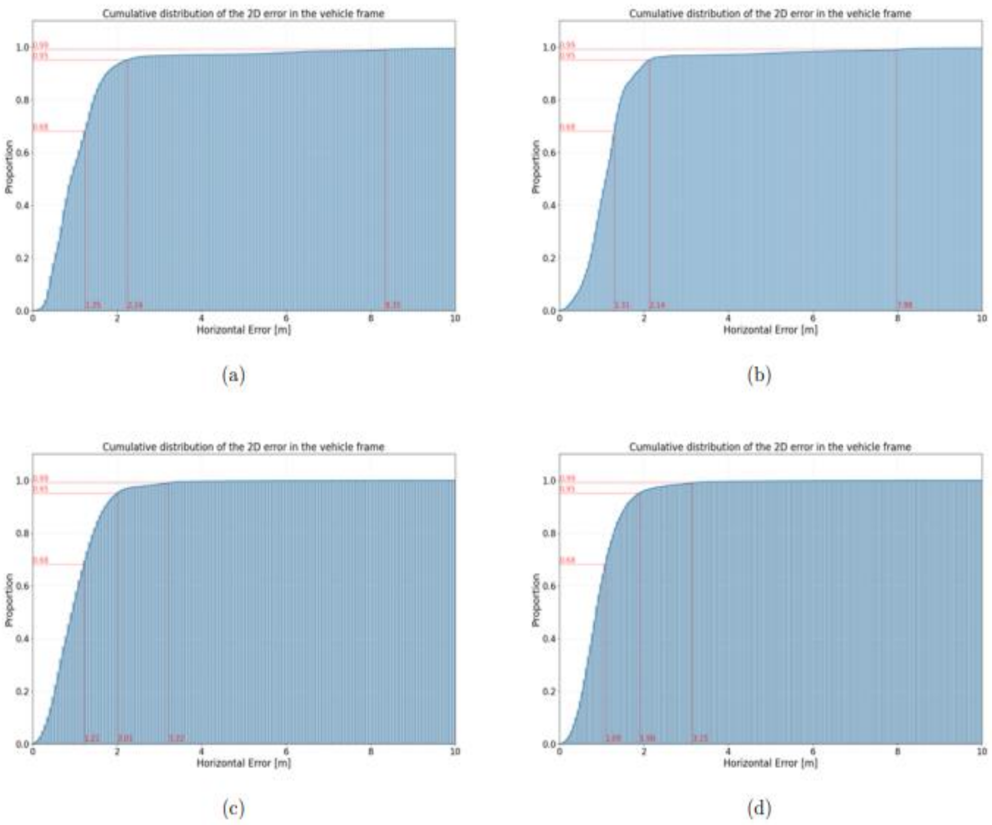


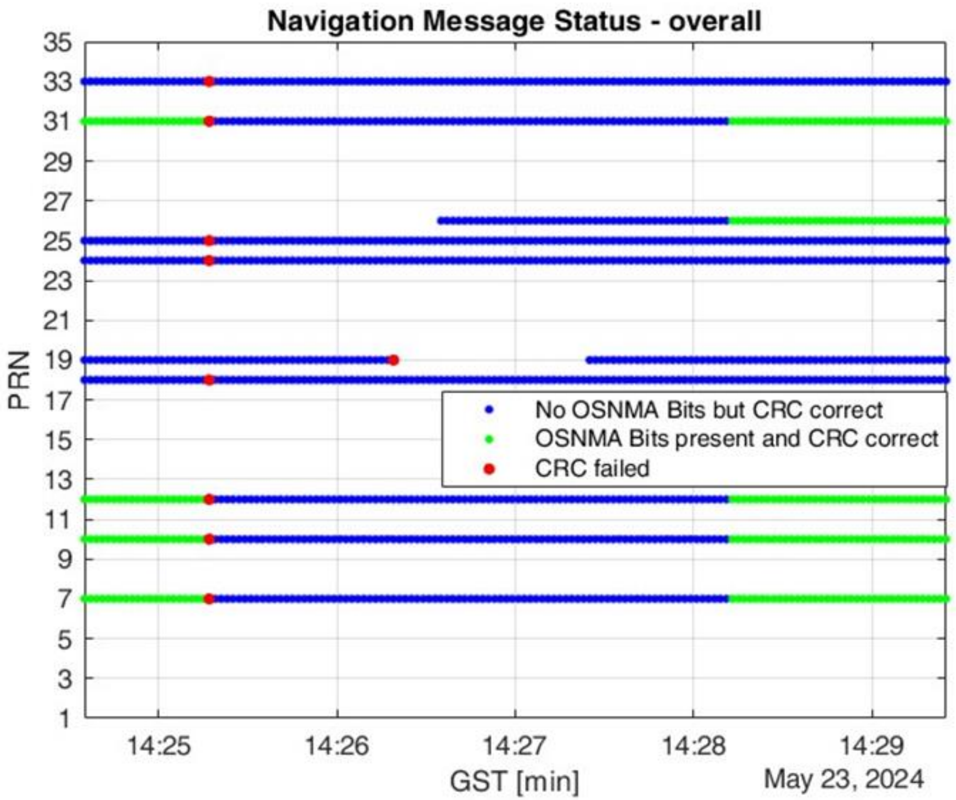
Spectrogram associated to test case 5A

J/S, in particular, spoofing events can occur. Therefore, for safety-critical applications the PNT algorithms must be robust to cope with this.

Novel Galileo Services & RF background

HAS & OSNMA





The overall navigation message status analysis indicates that the receiver could not acquire OSNMA data around the second minute, which coincided with the beginning of the spoofing test. Availability of the OSNMA bits seems to be a reliable indicator of spoofing, contrary to the CRC correctness. Postprocessed using the MUSNAT SDR.

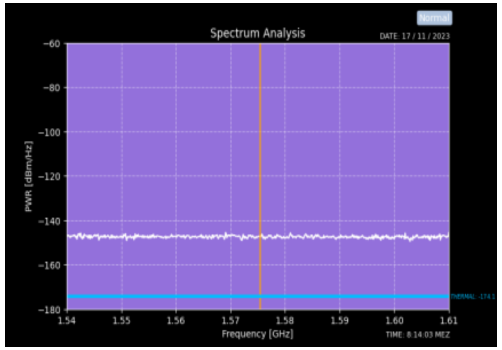
Results of using HAS improved about 10 cm for both static and dynamic conditions. The HAS performance is highly dependent on the environment.

OSNMA important mostly for starting and monitoring operations due to the 30 s latency.

L-Band environmental RF background

The ITU forbids any type of interference in the GNSS radio band, due to its universal usage, importance and critically.

Unintentional RF



Nominal background noise environment.

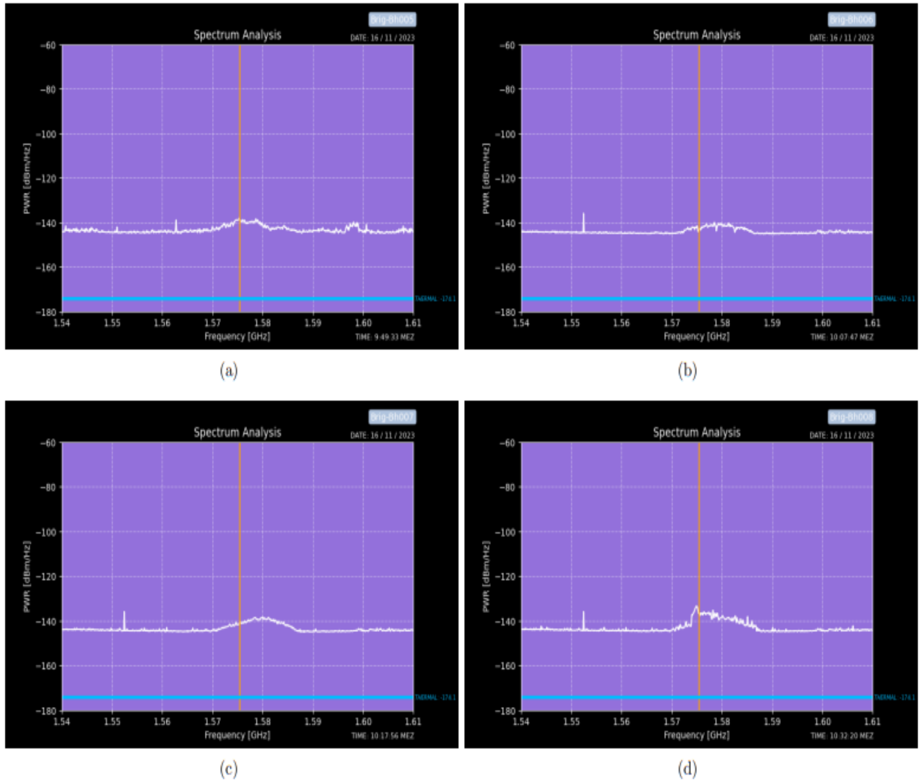


Figure 5.4: Day 16/11/2023 (a) Brig 05 (b) Brig 06 (c) Brig 07 (d) Brig 08

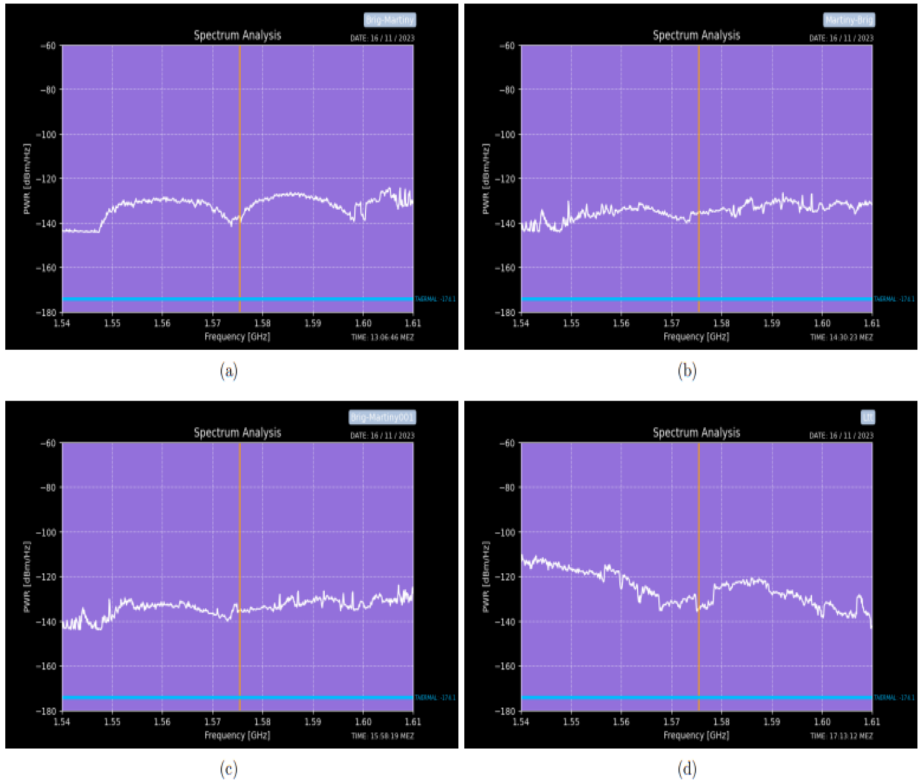


Figure 5.5: Day 16/11/2023 (a) Brig-Martiny (b) Martiny-Brig (c) Brig-Martin (d) Brig LTT

Measurements taken during the pre-campaign in November 2023.
Examples: of maximum RMS spectral density value along several routes travelled.

Measurement Campaign

”Funkmesswagen” MEWA12

- Telecom Measurement Wagon (GSM-R and Public Providers)
- Covers the Swiss railway network once per year
- Dedicated measurement trips in the Swiss Alps, shunting operations, all regions and landscapes

Sensors and Setup

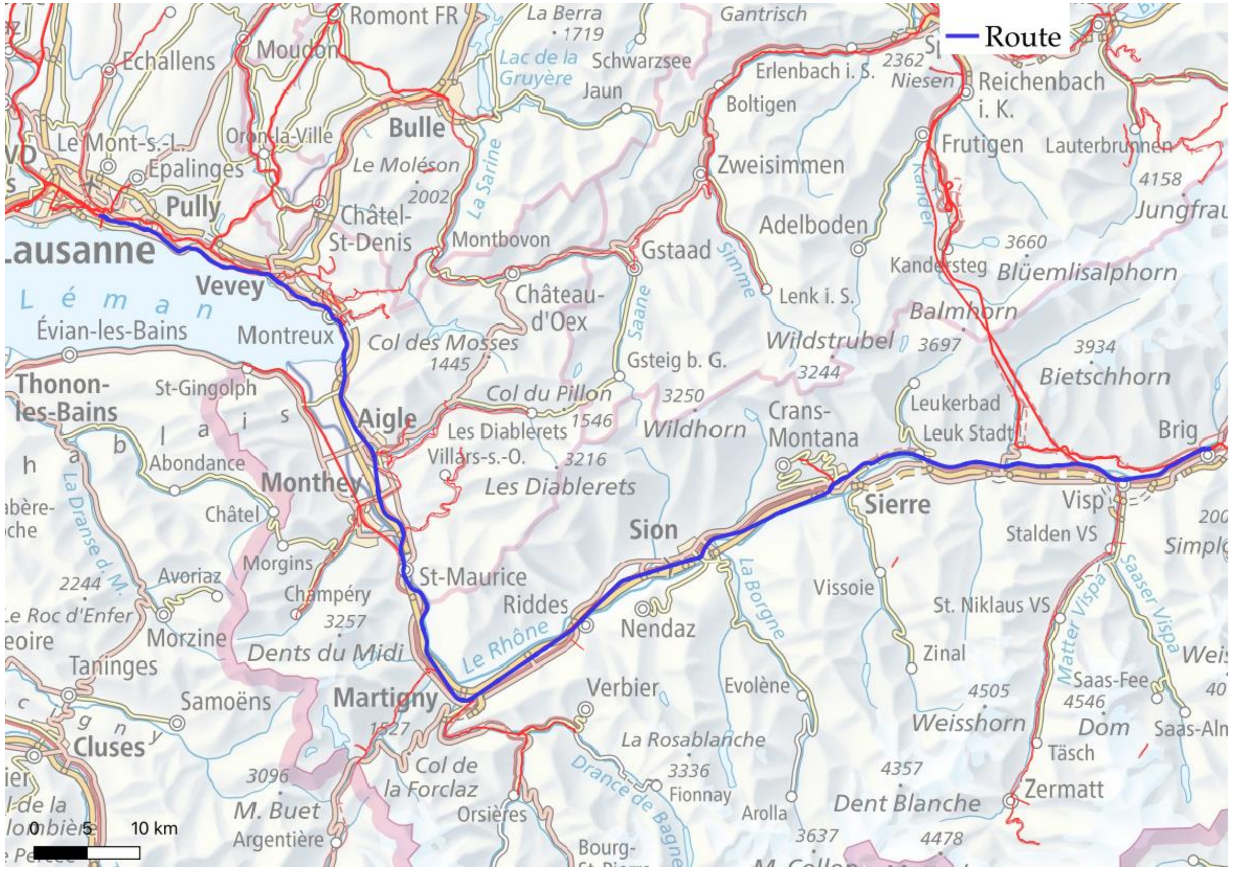
Inertial Navigation System iMAR RQT together with Balisereader for Ground Truth

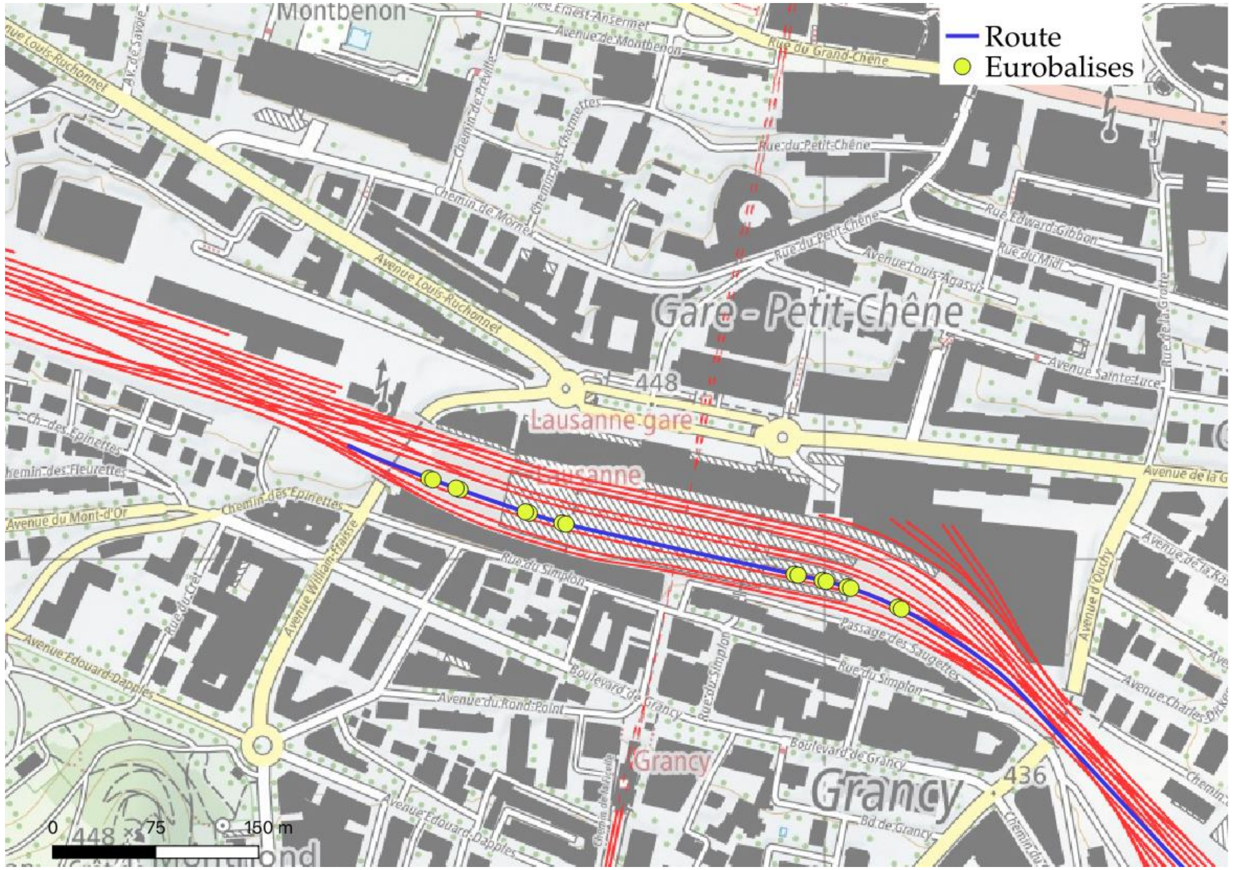
Inertial Navigation System iMAR M200 with tactical-grade IMU and Novatel GNSS receiver as sensor input

GNSS-Receiver Septentrio AsteRx-U

Optical Odometry Sensor HaslerRail CORRAIL1000

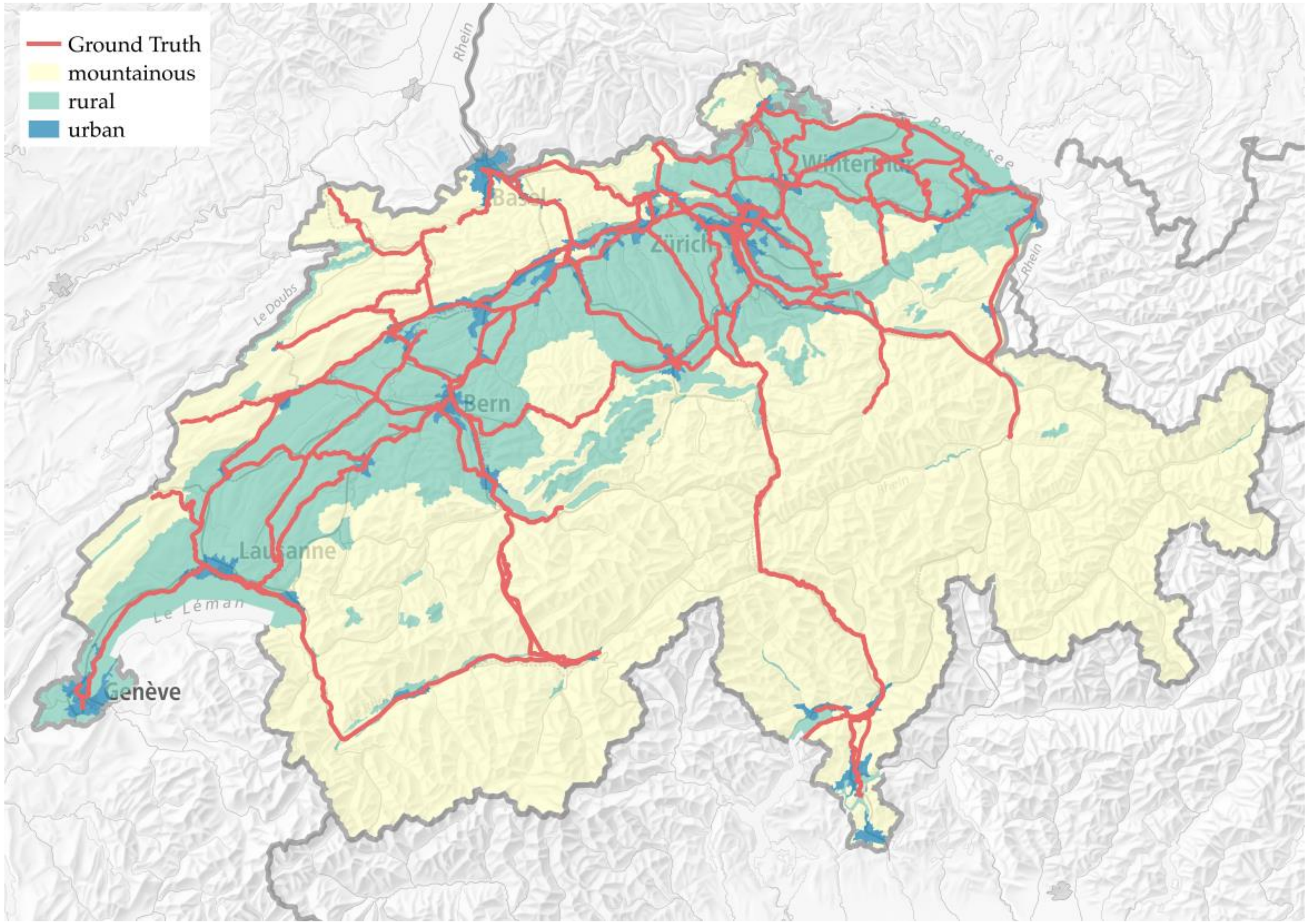
Map and Route Data





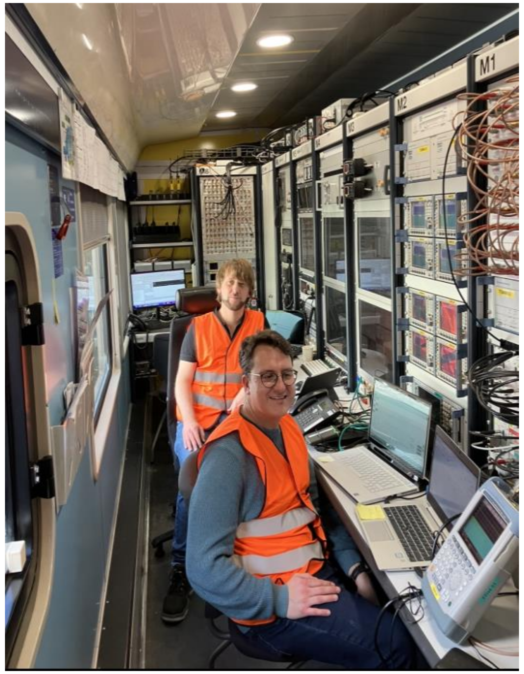
Test Data Set

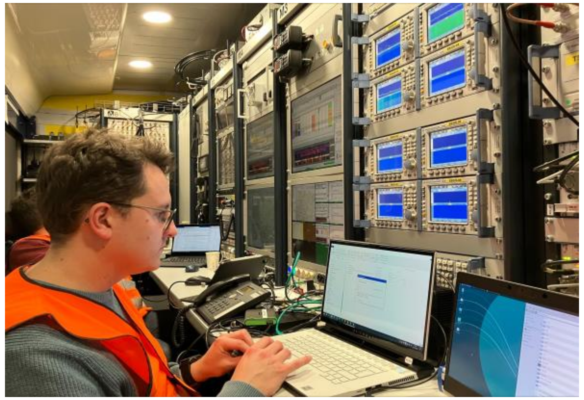
Parameter	Value
Number of train runs	400
Period	2023-09-08 - 2024-06-18
Duration of measurements	275 h
Covered distance	17'190 km
Minimum and maximum duration	2 resp. 290 min
Minimum and maximum covered distance	1 resp. 305 km



Two dedicated Measurement Campaigns

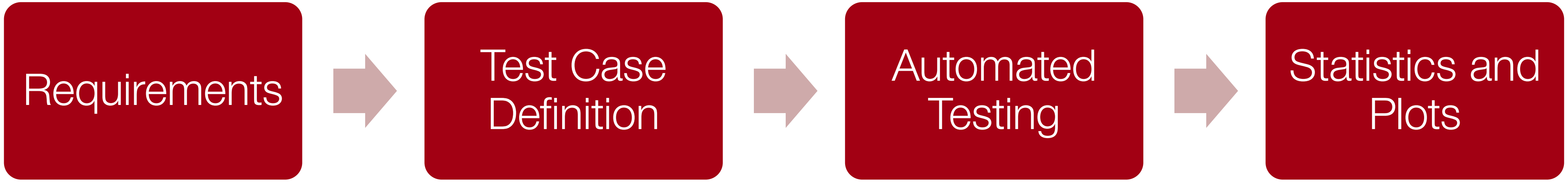
- Alpine region (Lötschberg) and Shunting operation in Brig in November 2023
- Jamming and Spoofing Test Campaign in Mai 2024





Big Data Analysis

Testing Process

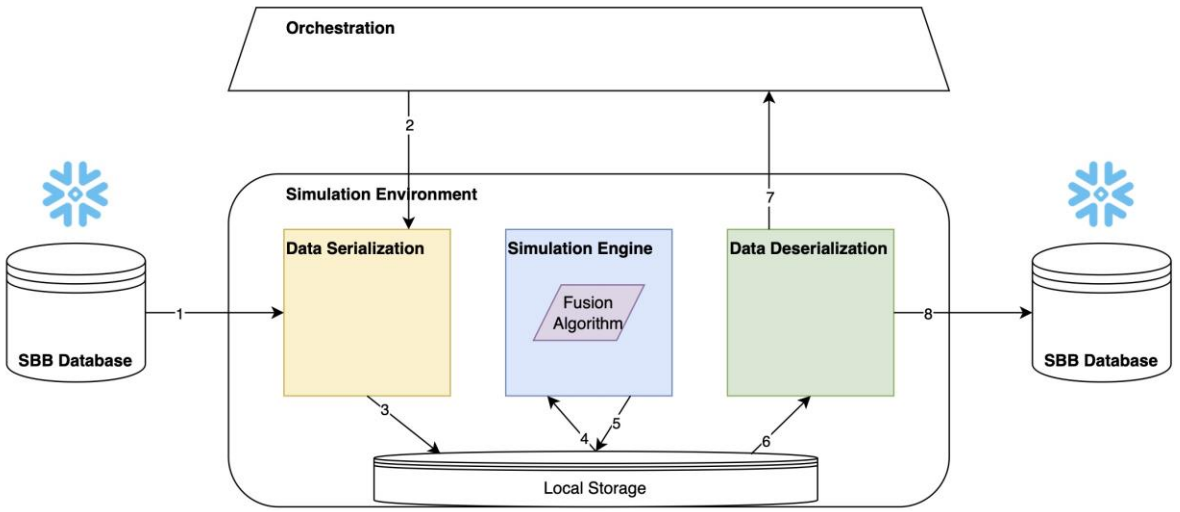


Automated Testing:

- Generate Algorithm Output and Ground Truth
- Define Boolean or statistical tests for the requirements
- Interpolate Ground Truth to Algorithm Output timestamps
- Check for each Algorithm Output sample if each test condition is fulfilled
- Generate statistics and plots

Simulation Environment

- Post-processing of algorithm implemented in ROS
- Generic message definition: https://github.com/EGNSS-MATE/emate_ros
- Specified input and output: https://github.com/EGNSS-MATE/egnss-mate-schematics
- **Simulation environment** can execute **any algorithm** fulfilling the message specifications with **any train trip** and **any sensor combination**



Advantages of ROS

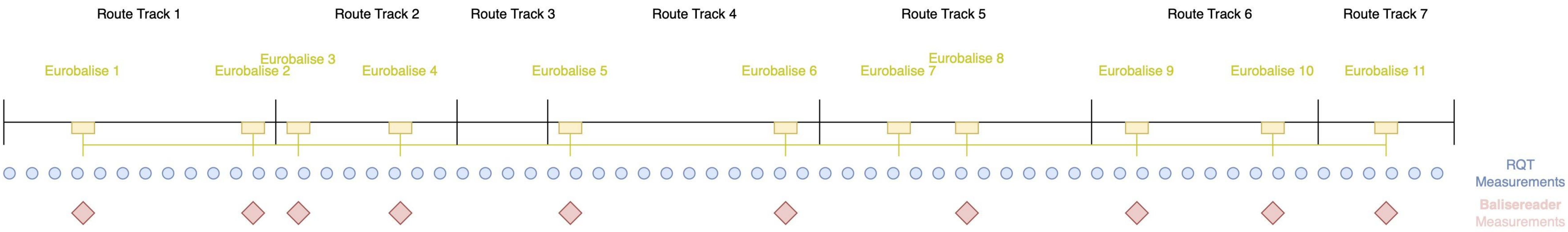
- ROS: Robot Operating System[1] (messaging and services framework)

- Replay as well as near real-time implementation are identical
- Handling of parameters, transformations, timing, messaging format, replay speed, common services, …
- Allows multiple implementation languages (Python, C++, …)

- The implemented Simulation Environment allows to process several hundred operation hours in a few hours automatically.

[1] https://www.ros.org/

Ground Truth: Multi-source validation



1. Fault Detection & Exclusion
2. Eurobalisen Position
3. Track Sequences
4. Eurobalise Sequences
5. Accuracy while Eurobalise passing
6. Accuracy to Track

Example

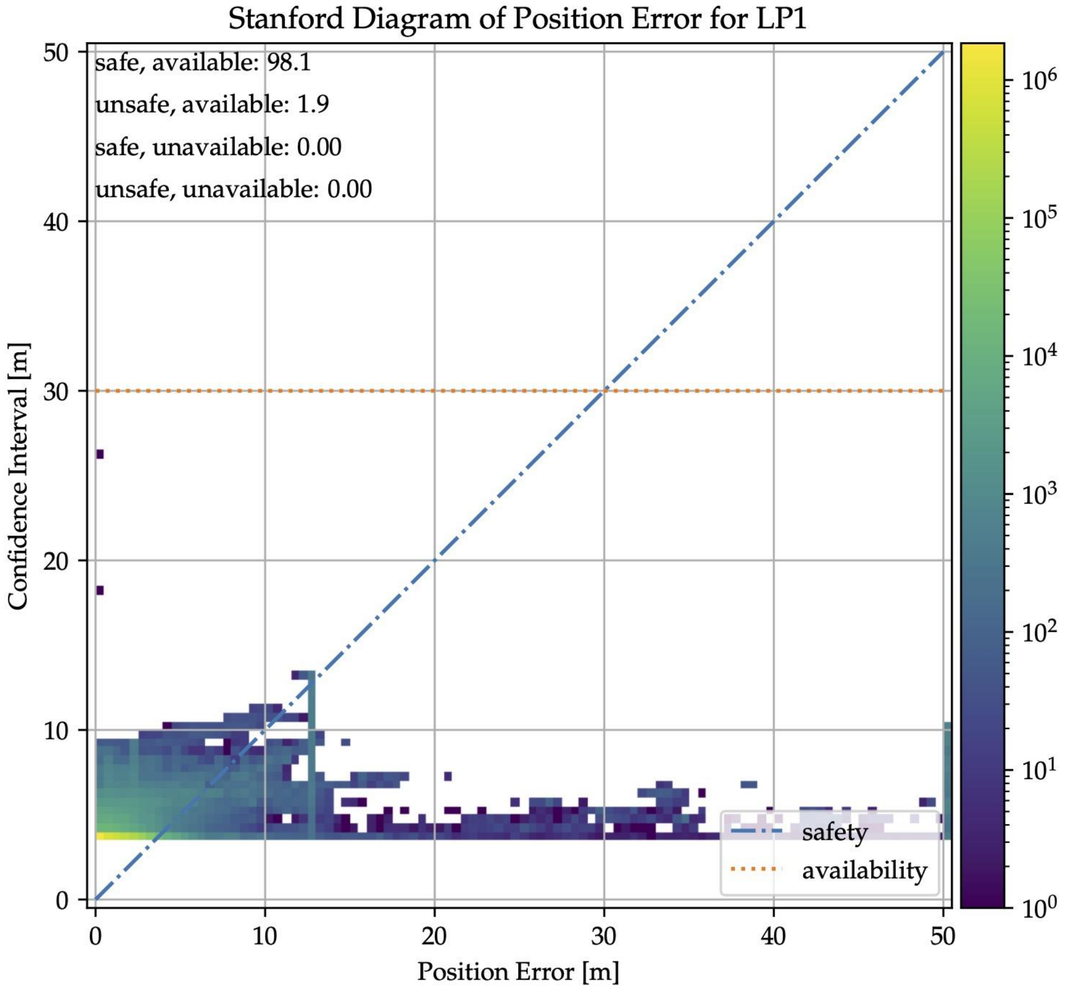
T5000-Y11-A

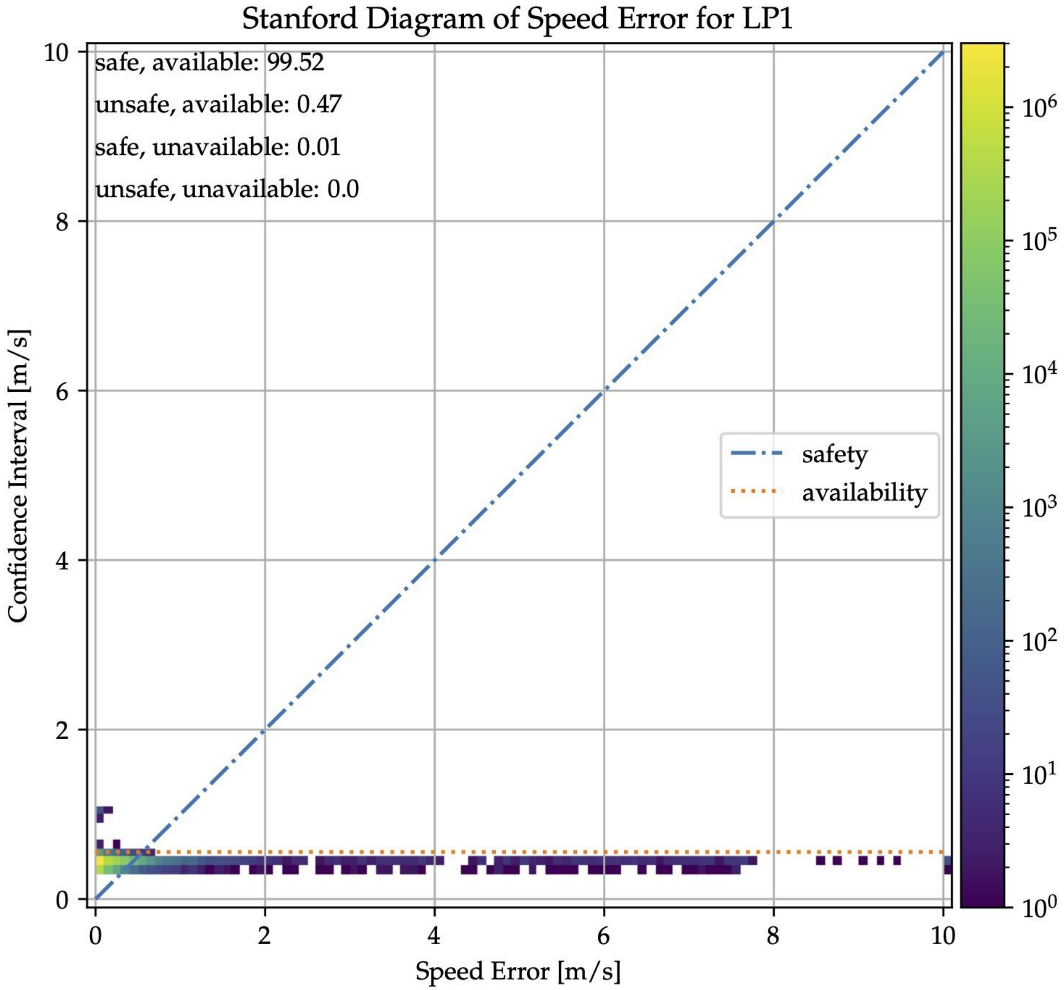
- System Requirement: FR 11: Requirement Track Selectivity
- User Requirement: UR 1
- Description: The system shall provide track selectivity at all times, excluding the exemptions listed below. This means that only a single correct track ID is provided. This excludes special cases with limited or compromised GNSS reception and short time intervals when passing switches.
- T5000-Y11-A: The number of estimated tracks shall be 1 or the number of used satellites is below 5.
- Localisation Profiles: LP1, LP2
- Condition: Status 0,1,2
- Discussion: The test is passed with significant margin above 50 percent of the data.

Result (P/F)	LP1		LP2		LP3	
Total	78.82 %	21.18 %	89.00 %	11.00 %	N/A	N/A
Urban	79.53 %	20.47 %	89.00 %	11.00 %	N/A	N/A
Rural	84.54 %	15.46 %	-	-	N/A	N/A
Mountainous	70.51 %	29.49 %	-	-	N/A	N/A

LP1: En Route
LP2: Shunting
LP3: Start of Mission

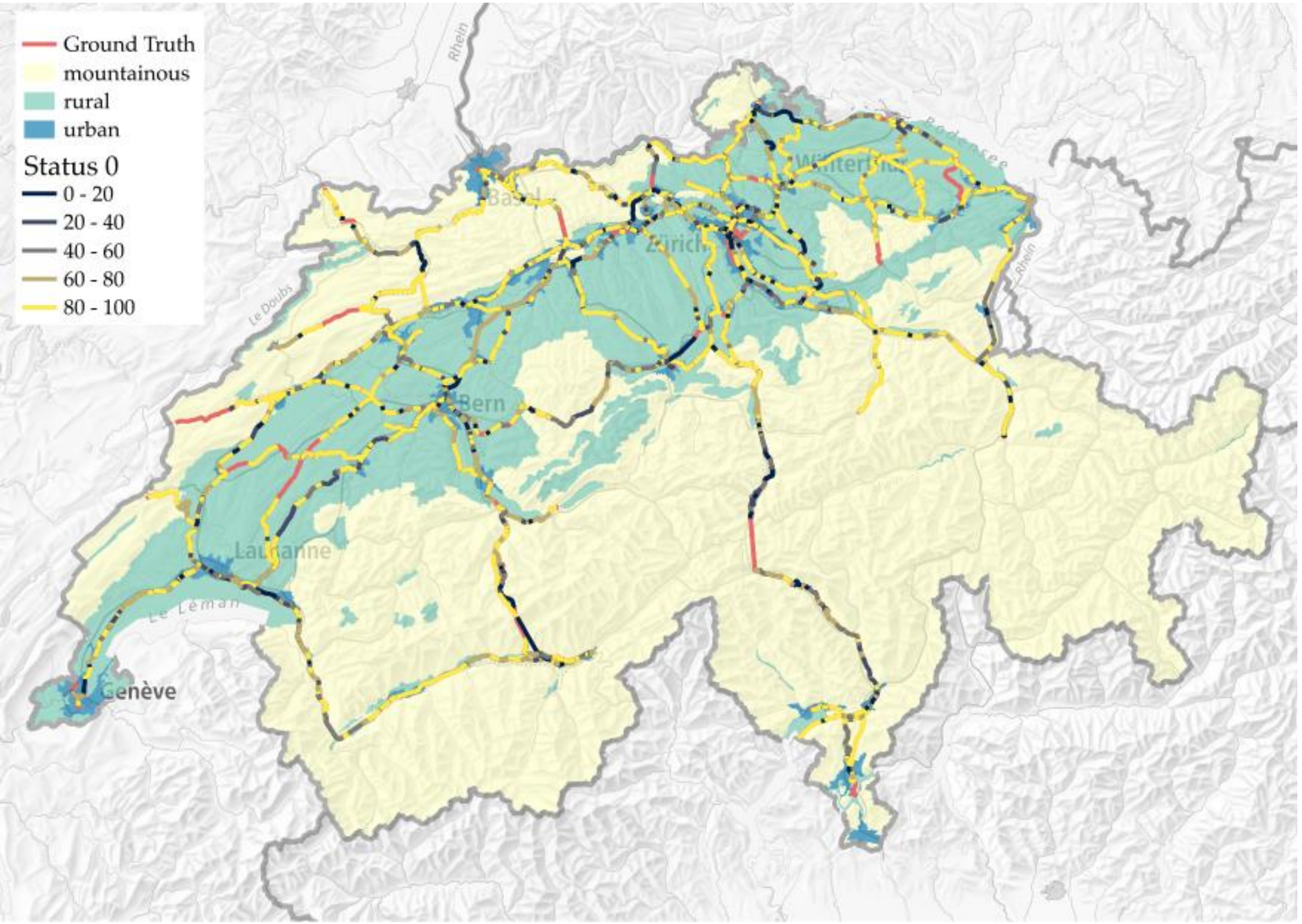
Plots of Statistical Analysis





Map Generation

Availability Map:

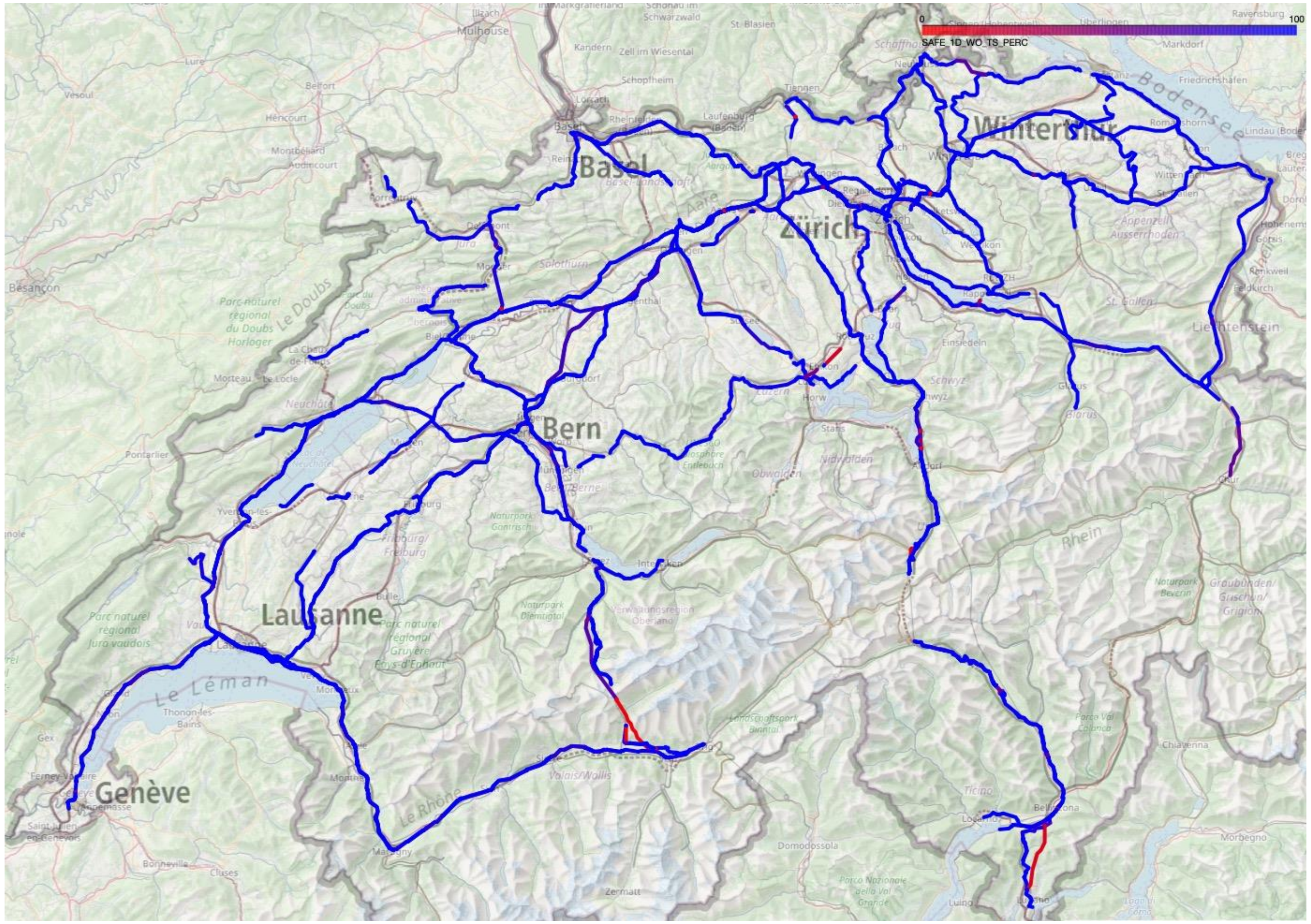


Whitelist Map without Track Selectivity

The map shows the percentage for each track edges for which the requirements for safe positioning without considering track selectivity are fulfilled.

This means:

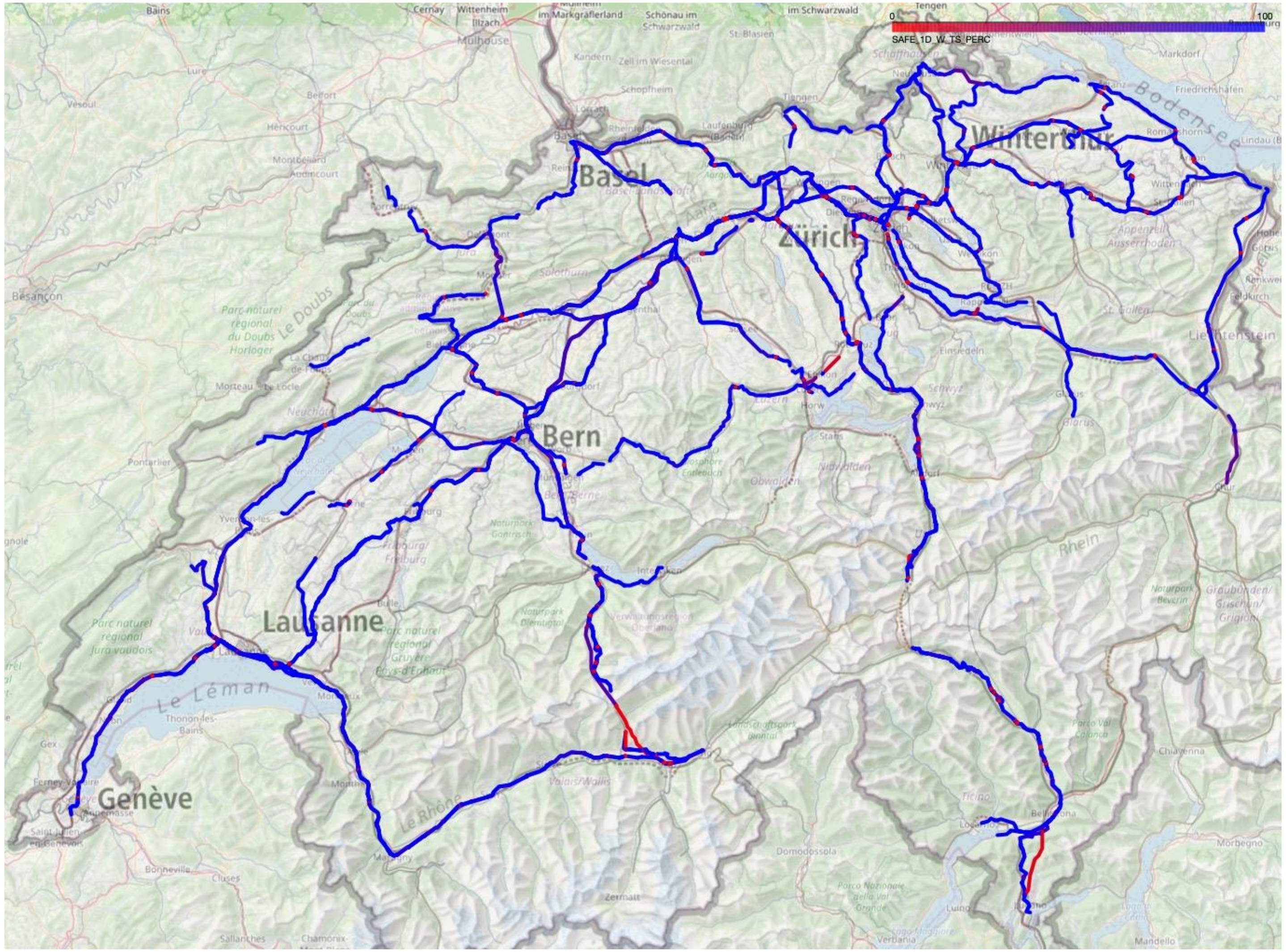
- Integrity is given
- Performance requirement is met



Whitelist Map with Track Selectivity

If we add the track selectivity requirements.

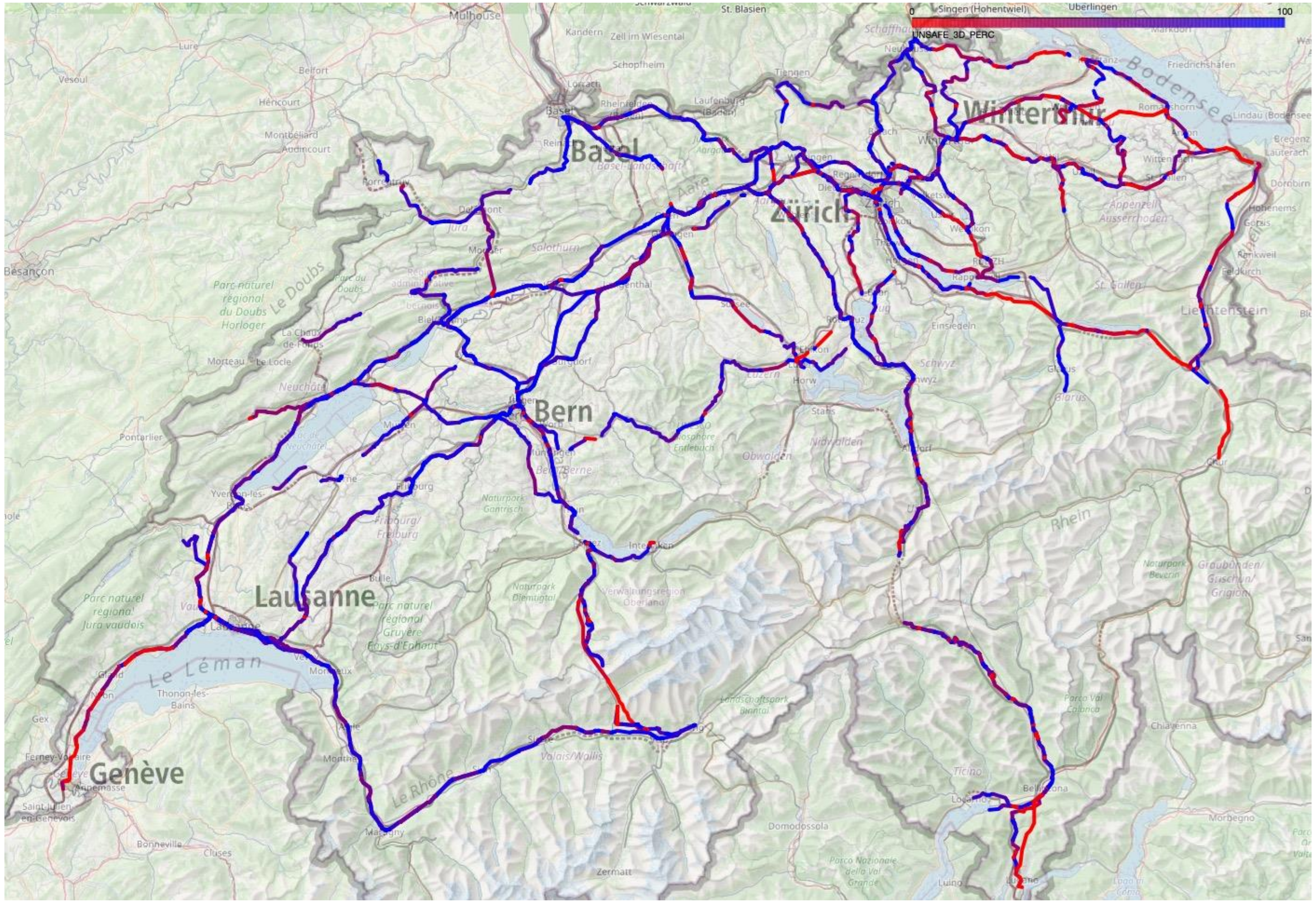
There are more track edges (especially around switch points) where the requirements are violated.



Whitelist Map for Global Position without Safety Requirements

Requirements for non-safe positioning:

- High accuracy targets can not be met on some lines.



Conclusions

And what’s next

Conclusions

Main Results:

- Map-supported localisation algorithms were developed and prepared as open source software toolbox
- A large dataset was collected with a ground truth reference
- The dataset was used in a simulation environment to do large scale testing of the algorithm
- Jamming and Spoofing Testcases were developed and implemented
- OSNMA could be useful for Start of Mission scenarios

Commercialisation and Future Work

The consortium members will continue to work on the topic of safe train navigation, through:

- Providing inputs to the standardisation activities based on the EGNSS MATE results
- Provide testing services to test GNSS receivers based on the jamming / spoofing test catalogue
- Advancing the localisation algorithms and software toolbox for various use cases and stakeholder needs
- Algorithms, data sets and test catalogue can be shared with interested parties

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SBB CFF FFS
Thank you for your attention