Juliette Marais Keynote, 02/06/2022

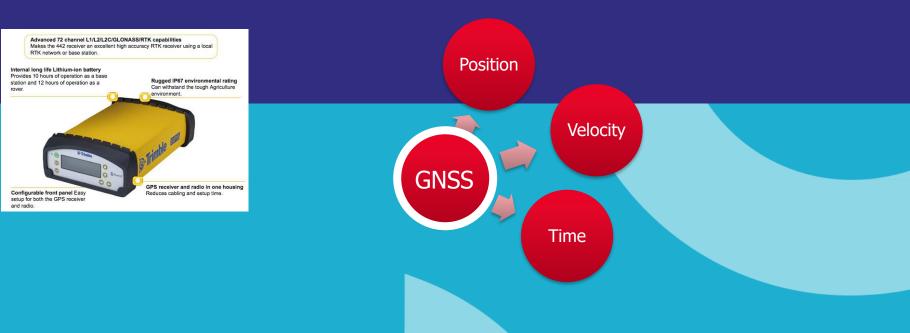
> Satellite-based train localisation for safety critical applications. The challenges of performance demo and certification







What are we talking about?





SATELLITE-BASED POSITIONING SYSTEMS

Global Navigation Satellite System

GNSS =

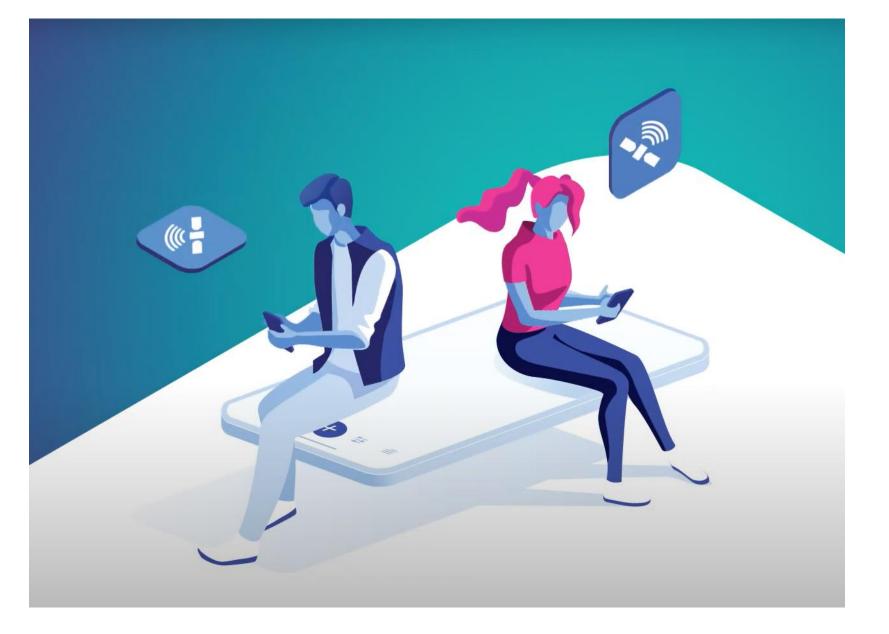
Generic term that concerns every satellite-based systems (including GPS)







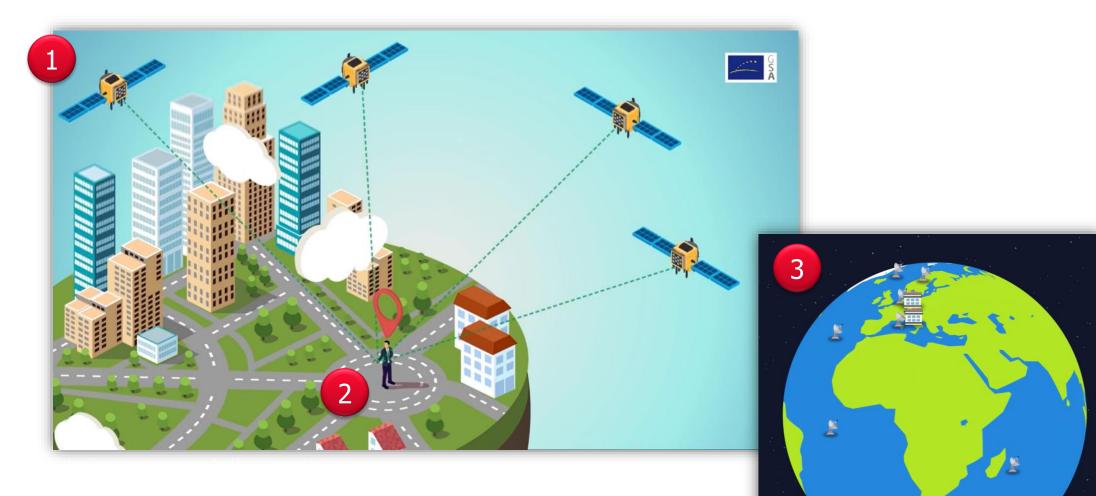
YOU HAVE A « GNSS » IN YOUR POCKET!



What? How?

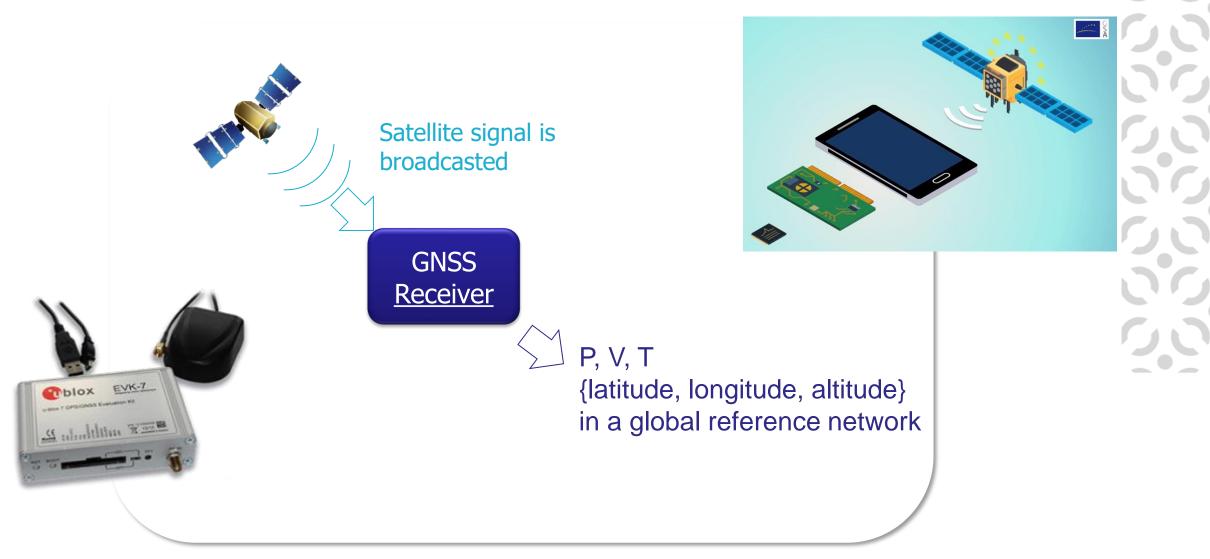






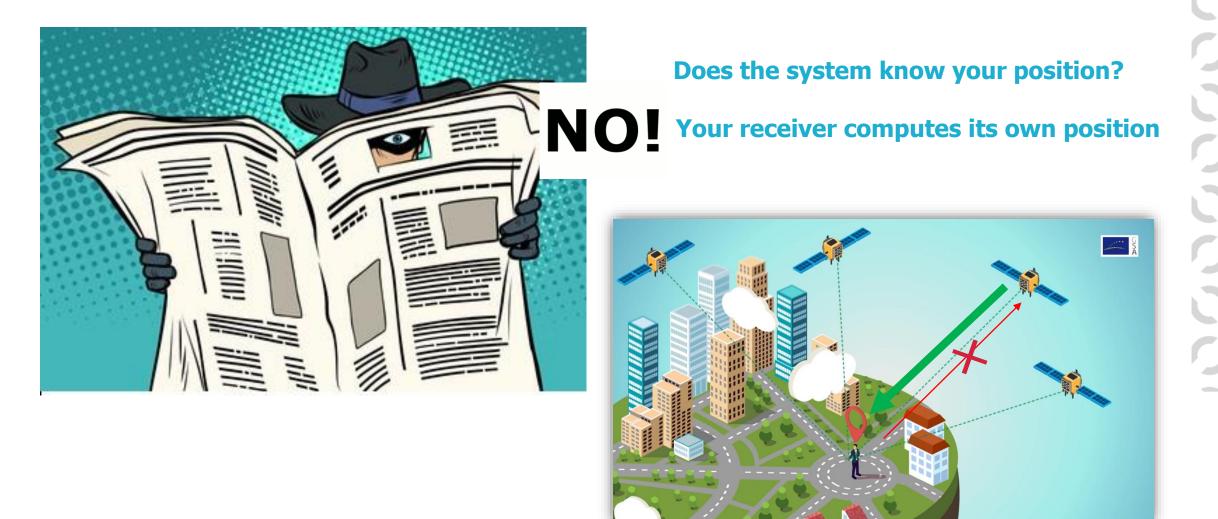


WHAT YOU HAVE IS A GNSS <u>RECEIVER</u>





ARE GNSS SYSTEMS SPIES?



With a GNSS receiver alone, no com.



THE INTEREST OF COMMUNICATING...





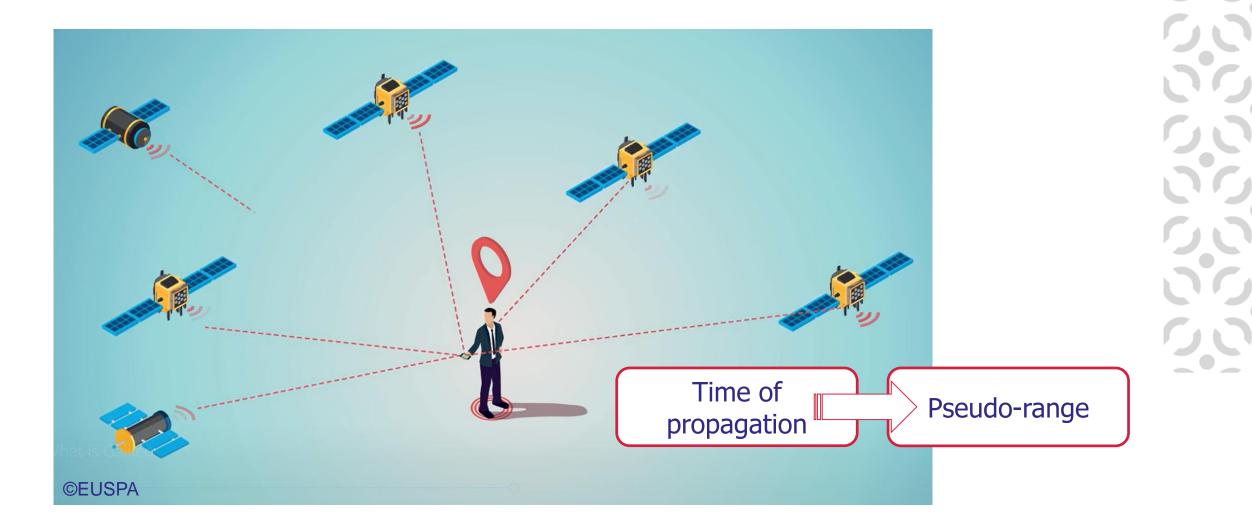




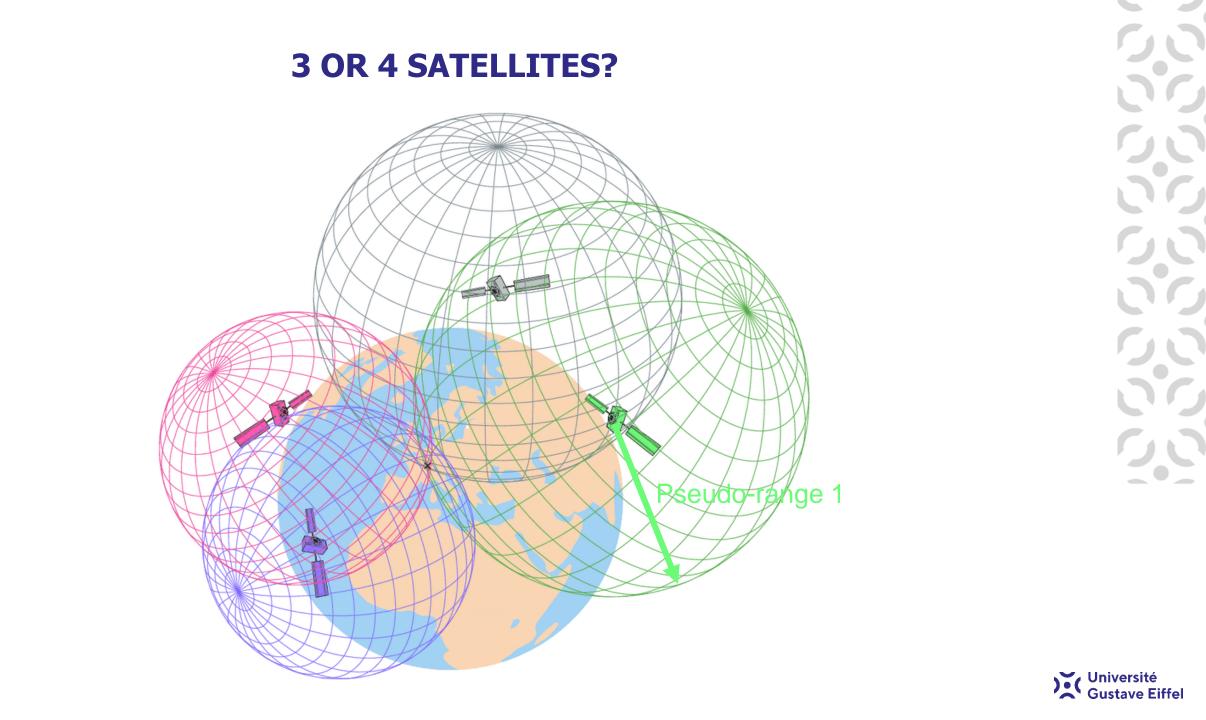




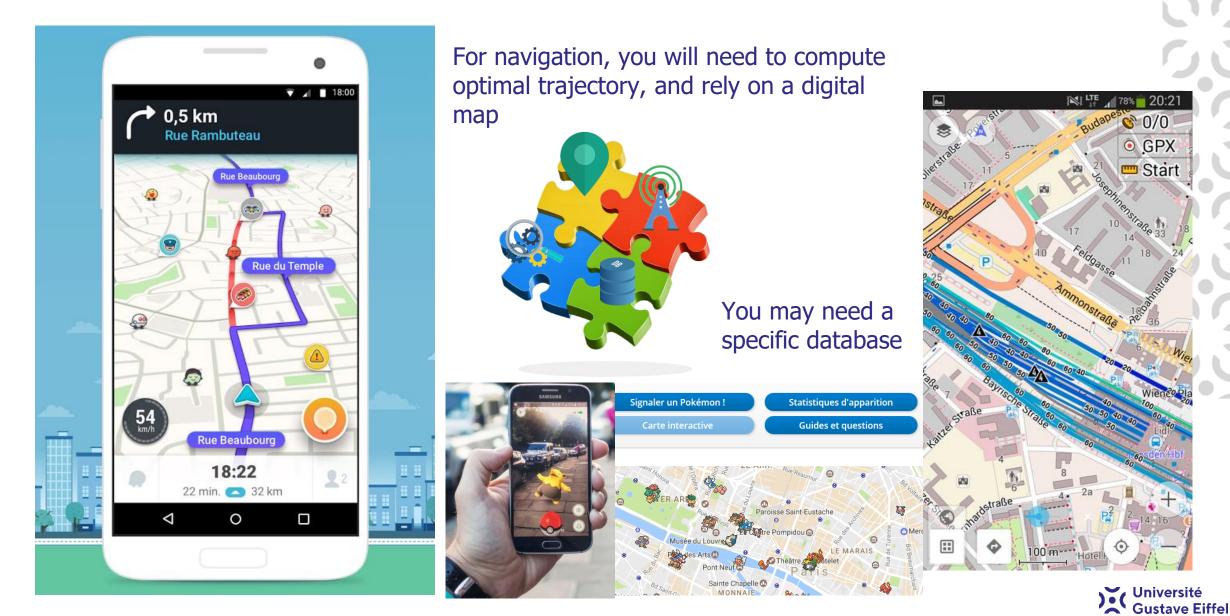
BASIC PRINCIPLE





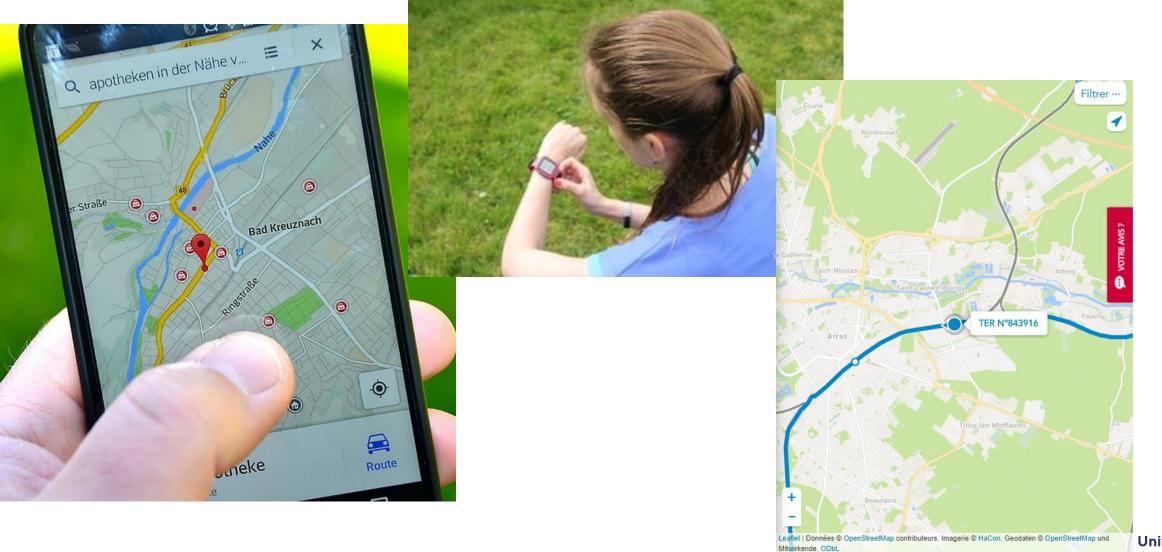


FROM POSITION TO APPLICATION



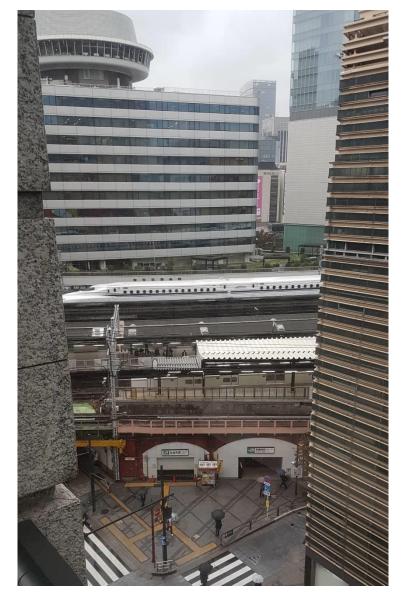


« GOOD » MOST OF THE TIME!



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WHAT ABOUT AVAILABILITY?



WHAT ABOUT ACCURACY?





DO YOU TRUST YOUR GNSS RECEIVER?







RAILWAY REQUIREMENTS FOR LOCALISATION

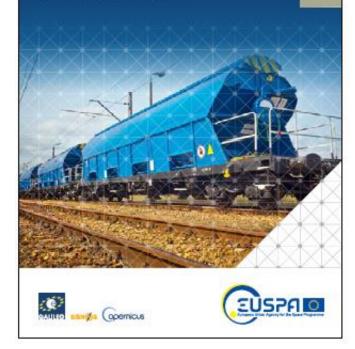
Non-safety vs safety

		Non safety-critical applications		Safety-critical applications
Applications	Asset management	Passenger Information	Trackside personnel protection	Signalling and train control applications
Key GNSS requirements	Accuracy (10 metres) Availability (High)	Accuracy (5 to 100 metres) Availability (95%)	Accuracy (1 to 10 metres and track discrimination) Availability (95%)	Accuracy (1 to 20 metres) Availability (High) Integrity Robustness
Other requirements	Connectivity Power Consumption	Connectivity (communication link)	Connectivity (communication link)	Interoperability

https://www.gsc-europa.eu/sites/default/files/sites/all/files/Report_on_User_Needs_and_Requirements_Rail.pdf



USER CONSULTATION PLATFORM



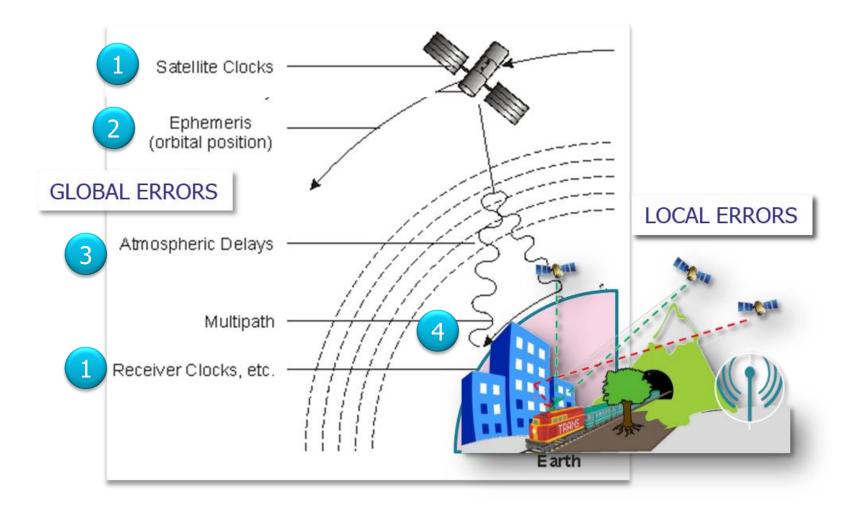
Ö



GNSS LIMITS



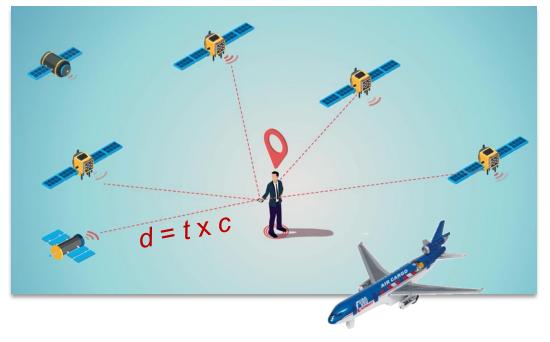
All starts with time propagation measurement...





IN RAILWAY ENVIRONMENTS AS IN ANY GROUND TRANSPORT ENVIRONMENT...

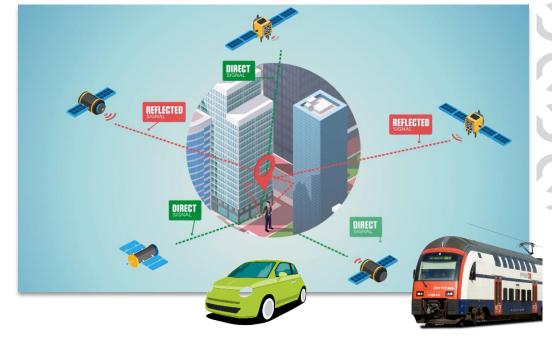
Variation of the performance in time and space



Optimal conditions of signal reception

Global errors/known models

vs Land transportation systems

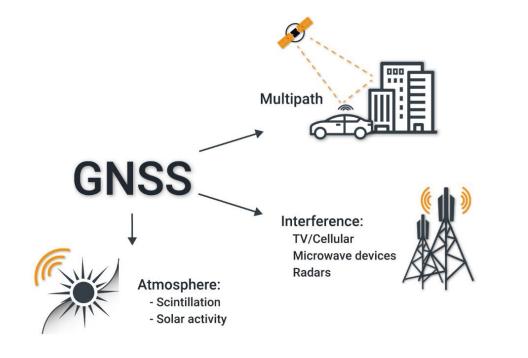


Local errors/unknown models



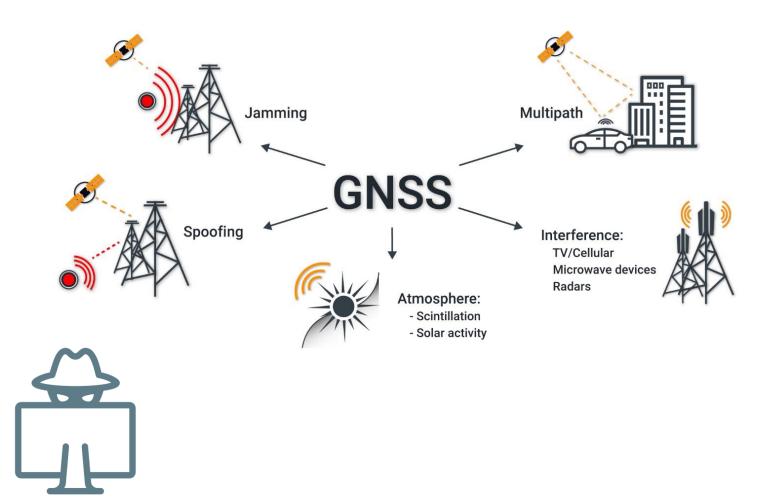


IT IS ABOUT SURROUNDINGS





IT IS ABOUT SURROUNDINGS







Université Gustave Eiffel

GNSS IS VULNERABLE

Russia is jamming GPS satellite signals in Ukraine, US Space Force says

By Elizabeth Howell published 14 days ago

'Ukraine may not be able to use GPS,' a Space Force official told NBC.

1 🖸 🚳 🖗 🔽 🖸



GPS services appear to be under threat in Ukraine. (Image credit: Lockheed Martin and U.S. Space Force)



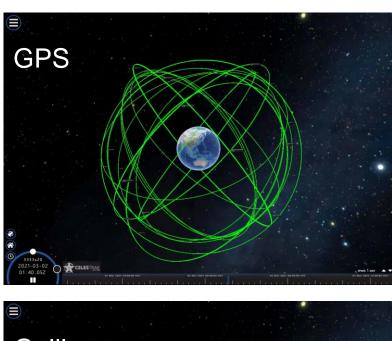
New GPS 'circle spoofing' moves ship locations thousands of miles

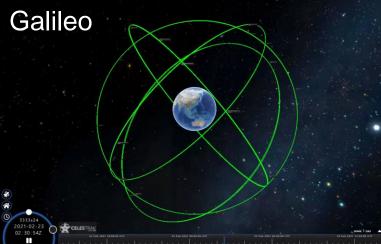
May 26, 2020 - By Dana Goward

Est. reading time: 2 minutes 🕒



IT IS ABOUT TIME TOO...





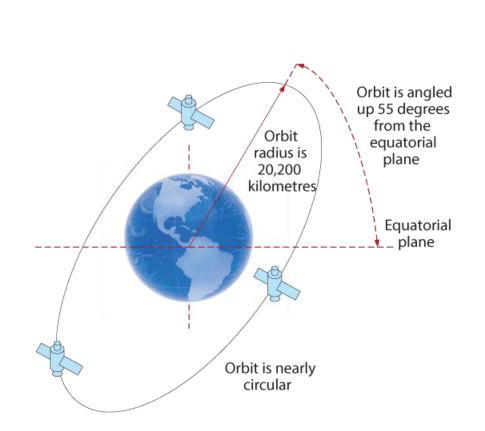
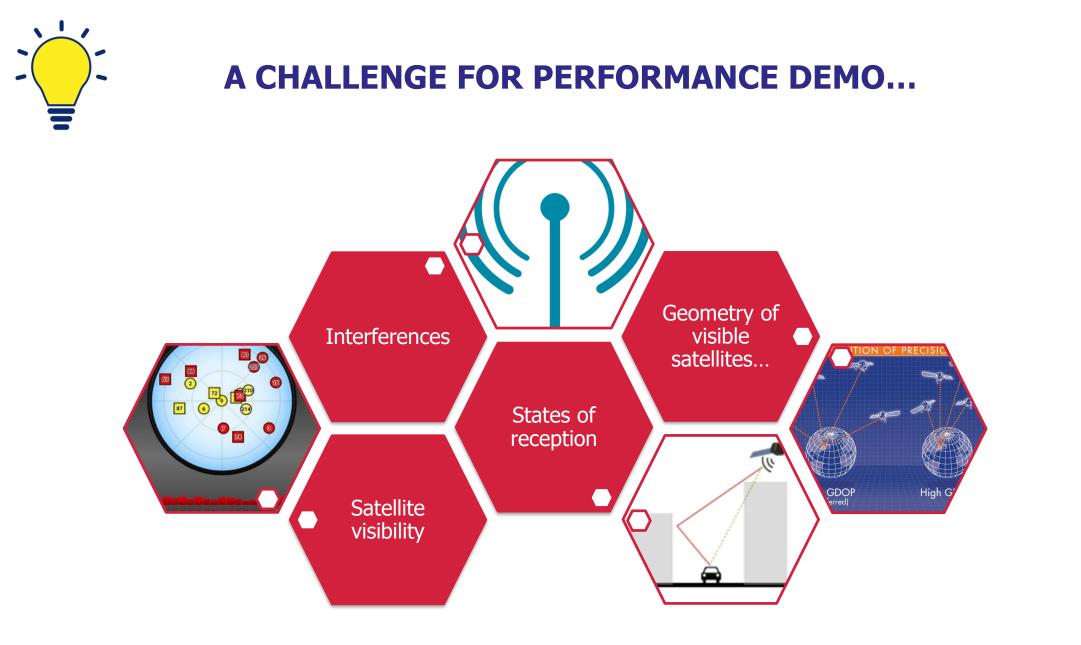


Figure 28 GPS Satellite Orbit







SO... DO WE REALLY WANT TO USE GNSS???





There are many reasons to have GNSS onboard!

⊘ Continuous absolute position, 24h/24h, 7/7

- ⊘ No borders
- \odot « Cheap » chips
- ⊘ On-board equipment (no infra)
- ⊘ No fees

⊘ New services (i.e. signal authentication, High accuracy...)



GNSS FOR RAIL

What will be facilitated with GNSS for rail?



Attractiveness

New services for clients

- Passengers,
- Freight customers



Efficiency

Improve maintenance

- Real-time diagnostic -
- Anomaly detection and localisation
- Predictive maintenance -



©Traxens/SNCF Logistics









POSITIVE TRAIN CONTROL & SAFETY

Amtrak Accident **Renews Push** for PTC

he fatal derailment of an Amtrack passenger train in Washington state has, once again, prompted calls for installation of GPS-aided positive train control (PTC) systems on board American trains.

On December 18, 2017, passenger train 501 - a Talgo Incorporated locomotive on its inaugural passenger service trip --- went off the tracks at an estimated 78 mph in a 30-mph speed zone near Dupont, Washington, a small community between Tacoma and Olympia.

Passenger train 501 was equiped with PTC...but the system had not been activated ... because that section of the line had non been tested

PTC is designed to prevent...overspeed derailments...



natched against a map database show ing rail network layouts, signage, speed estrictions, and so forth. Shortly before the equipage deadline epartments of transr however, in the face of industry resistance and lack of progress on installing PTC aid that 51 percent of Amtrak's natio wide diesel locomotive fleet has PTC on their locomotives and rail networks. equipment installed, with 151 units cor missioned and ready to operate. ongress approved a three-year exten Rail operators now have until the end of this year to upgrade their systems - plu After the Fact

PTC continued from page 1 PTC is an advanced train

U.S. rail system.)

restriction and to stop the train

Ironically, Amtrak actually has a fairly

good record at trying to meet the PTC

another two years to actually get them working. (A Spring 2015 ION Newslette is with past incidents, in the wake of the article describes the basic architecture of Dupont derailment agency officials and PTC and the nearly 50-year effort by the soliticians weighed in on the need to in National Transportation Safety Board, or ement PTC for real this time. In Decen NTSB, to see its incorporation into the er 27 letters to the heads of the nation' ailroads, U.S. Department of Transporta Passenger train 501 was equipped with ion (DoT) Secretary Elaine Chao sent a PTC and the associated trackside infrareminder" to the rail officials of the PTC structure was in place, but the system had nilestones and stating the department' not been activated, reportedly because xpectation that the companies "will meet he requirements specified by Congress or that section of the line had not been tested. Properly equipped with PTC ar before December 31, 2018. switched on, if a train does not slow for In comments reflecting an initiative an upcoming speed restriction, PTC will that has been getting ready to get starte alert the engineer to reduce the speed. If for nearly 50 years, Chao added that appropriate action is not taken, PTC will ederal Railroad Administration (FRA apply the train brakes before it violates the officials responsible for overseeing the PTC mandate had been "directed to work In the Washington state Amtrak acciwith your organization's leadership to dent, an NTSB preliminary report stated that an operational PTC system would help create an increased level of urgency o underscore the imperative of meetir have notified the engineer of train 501 xisting timeline expectations for rolling about the speed reduction for the curve out this critical rail-safety technology If the engineer did not take appropriat Meanwhile, over on Capitol Hill, Peter action to control the train's speed, PTC would have applied the train brakes to DeFazio (D-Oregon), Ranking Member of the House Committee on Transporta naintain compliance with the speed ion and Infrastructure, and Michael

als, sent a letter to Amtrak President and he heads of the Oregon and Washington Chief Executive Officer Richard Anderso rtation, Amtrak requesting a detailed update on Amtrak's ident and CEO Richard Anderson y culture and imp Positive Train Control (PTC) on route owned or operated by Amtrak. Amtrak and other organizati responsible for the track where the accident occurred "should have . . . installed PTC, regardless of the December 31, trak's operation

2018 deadline mandated by Congres DeFazio and Capuano wrote. In respons to Amtrak's defense that it does not ow the locomotives or infrastructure over which Passenger Train 501 was operating the congressmen said, "As the operator, you are responsible for safety," adding that "Amtrak only reports on progre oward implementing PTC across rout and on equipment that Amtrak owns and controls, leaving out large portions of An Earlier this year, DeFazio, Capuar and seven cosponsors introduced a bill H.R. 4766, the "Positive Train Control plementation and Financing Act," that would prohibit another extension of the PTC deadline, provide up to \$2.5 billion in grants for intercity or commuter na enger rail companies to implement PTC and require any new passenger routes to have PTC implemented before they begin Of course, with its real-time position

ing capability, PTC has benefits beyond passenger rail safety. It could help freight as well as passenger railroads to operate Capuano (D-Massachusetts), Ranking more efficiently, enabling the companie Member of the Subcommittee on Rai to increase track capacity and use their roads, Pipelines, and Hazardous Materiassets more productively.



TODAY, GNSS RECOGNIZED AS A GAME CHANGER FOR ERTMS

EU Parliament calls for fast adoption of satellite-based train localization in railway signaling

Adoption of the own-initiative procedure 2019/2191 (INI) in July 2021, the European Parliament highlights the need to take advantage of the **potential cost savings that GNSS offers in railway signalling.**

The Parliament calls specifically on:

• The EU rail industry to develop technical solutions in order for the GNSS to enable the ERTMS on a large scale

- The European Commission (EC), to consider introducing the GNSS in the upcoming ERTMS TSI CCS revision in order to close the remaining technological gaps and embrace innovation
- European Railway Agency (ERA) to closely coordinate, support and streamline research and development projects of space and rail stakeholders in order to include GNSS train location data in the ERTMS as early as possible

• The cooperation between ERA and the European Union Agency for the Space Programme (EUSPA) to be stepped up in order to phase the GNSS into ERTMS standards



GNSS IS PART OF THE EU R&D PROGRAMS

Provide Digital Twins Design toolbox for design as well

as for validation, verification and test + a Federated

dataspace where all digital elements of the system can

Innovation on new approaches for

auided transport modes

play together in a coherent and interoperable way

EU-Rail Multi-Annual Work Programme

FA2 - ATO+

FA3 - Assets Mngt



Management in a multimodal environment

Network management planning and control (new processes and automation for decision support) & rail management in a multimodal environment (real-time demand-driven operations, including demand from other transport modes)

Digital & Automated up to Autonomous Train Operations

Digital "Automated & Autonomous" Train Operations building upon the next gen Automatic Train Control based on ERTMS + enhancements on TCMS for integration at the on-board level

Intelligent & Integrated asset management

Knowledge from the digital transformation will feed back into the design, construction, manufacturing as well as into operation and maintenance processes.

A sustainable and areen rail system

Innovative solutions and services based on leading edge technologies to minimize the overall energy consumption and environmental impact of the railway



and other activities

FA4 - Green Solution

FA5 - Freight

Explore non-traditional and emerging flexible and/or high-speed guided transport systems, as well as to create opportunities for innovators to bring forward ideas for shaping those future systems FA6 - Regional Regional rail services / Innovative rail services

FA7- new

Diaital Enablers



Sustainable Competitive Digital Green Rail Freight Services

Digitalization and automation of operational functions (e.g. DAC) and processes as well as increasing the efficiency of the immaterial (information/data) layer of transport in logistic

ESA SPACE4RAIL INITIATIVE

ESA Business Applications Space4Rail: An initiative supporting the exploitation of space-based assets to improve the performance, competitiveness and attractiveness of the railway sector

#Space4R

https://space4rail.esa.int/opportunities/ba-s4r

E-GNSS IN RAIL SIGNALLING



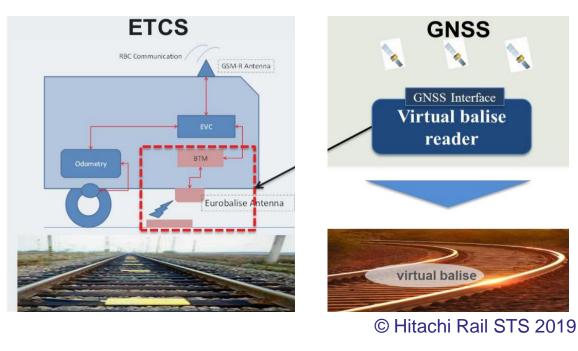


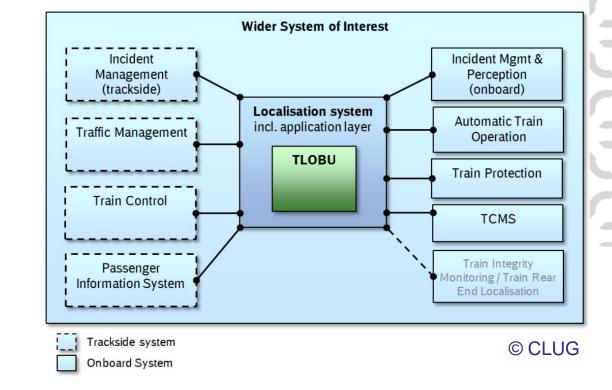


TWO // APPROACHES AND PROGRESSES

The use of GNSS for Virtual Balise

A continuous localisation of the train

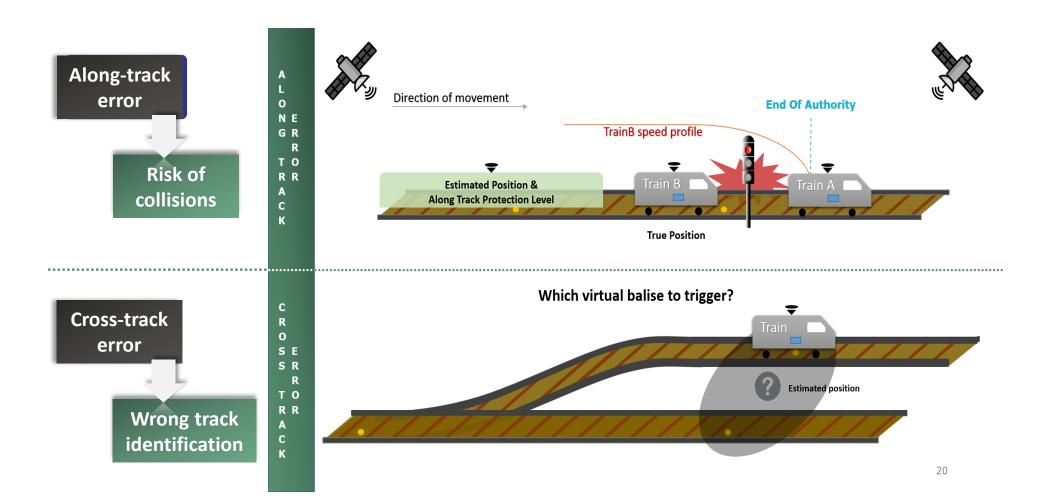






What are the challenges... ...in particular with local effects?

2 MAIN FEARED EVENTS

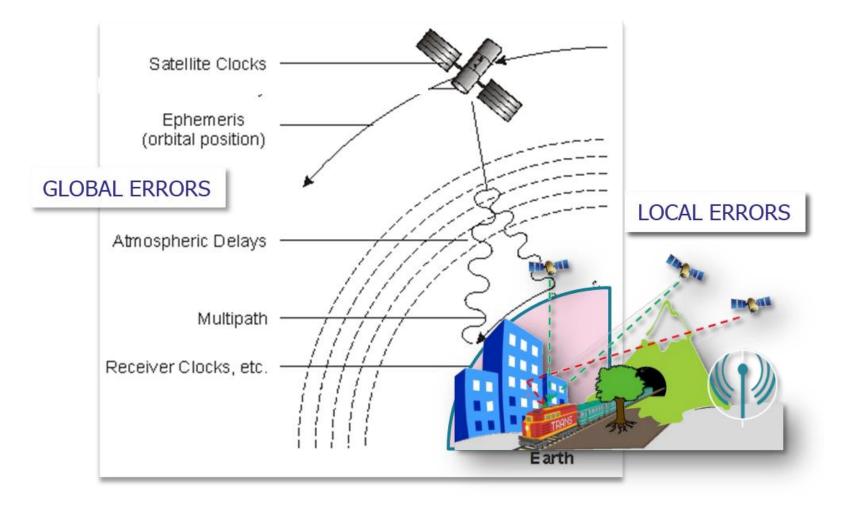




GNSS LIMITS



All starts with time propagation measurement...





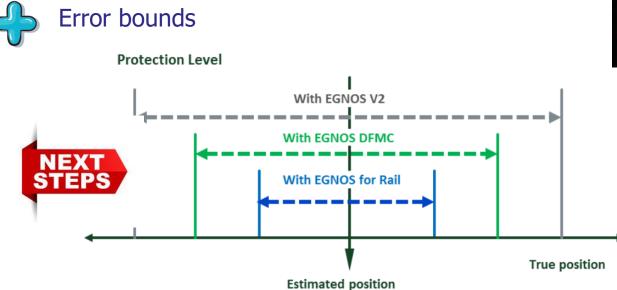
A 1st LEVEL OF ANSWER: EGNOS, for global errors

Satellite Based augmentation System (SBAS)

 \rightarrow in Europe : EGNOS



More accuracy (correct iono, orbits...) EGNOS improves the accuracy and reliability of GNSS positioning information



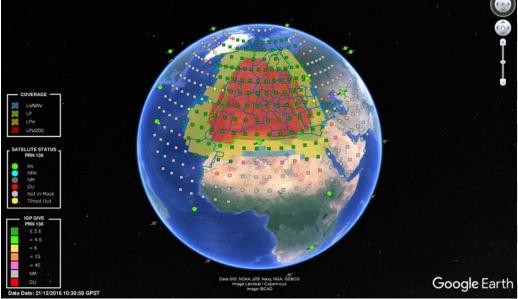




Figure 13: Qualitative train protection levels versus EGNOS versions ©CLUG

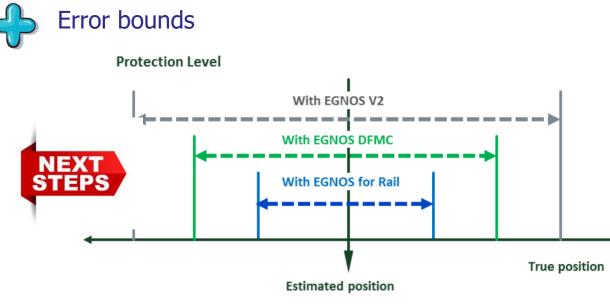
A 1st LEVEL OF ANSWER: EGNOS, for global errors

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 \rightarrow in Europe : EGNOS



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Cf. CLUG Recommendation (D3.4 Cf EGNSS-R project

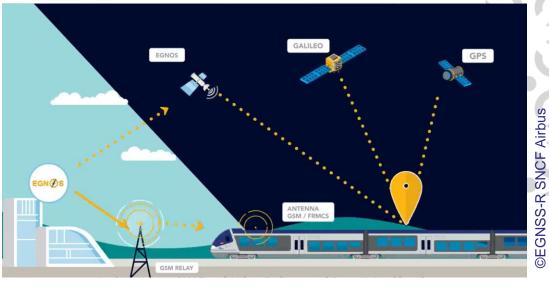
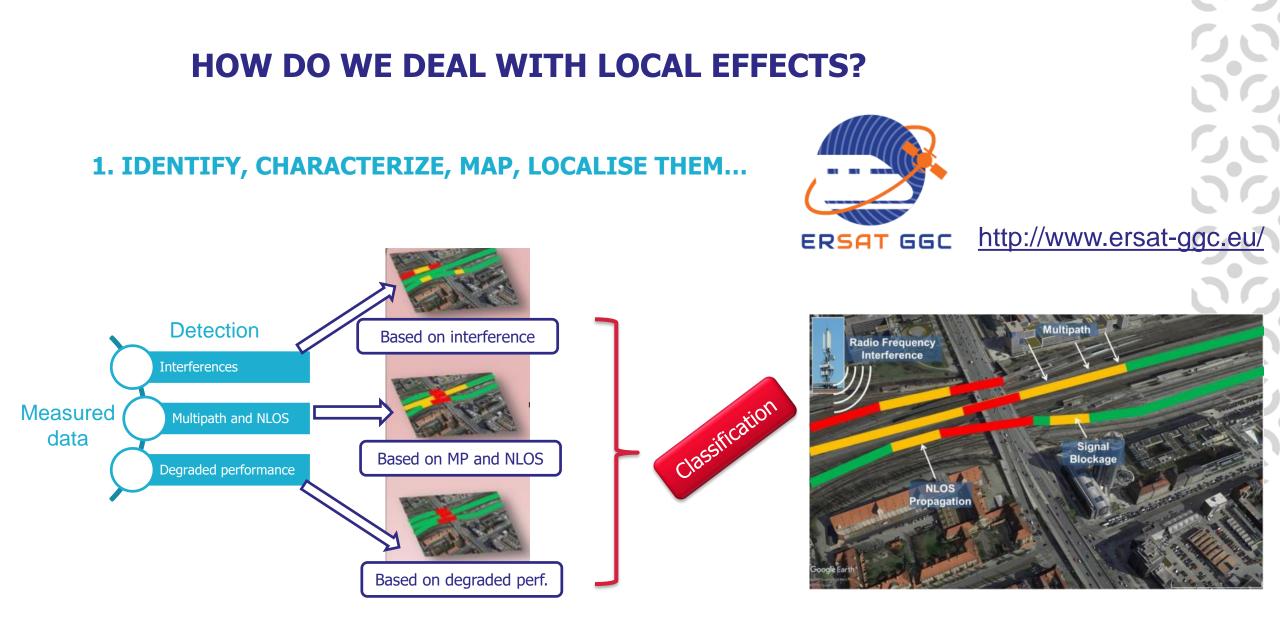




Figure 13: Qualitative train protection levels versus EGNOS versions ©CLUG



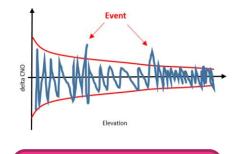




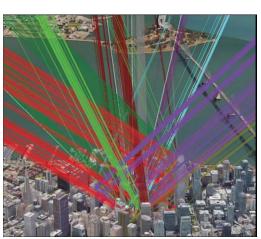


2. MITIGATE MULTIPATH

Multipath and NLOS detection and mitigation is highly investigated!

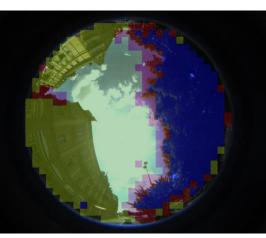


From raw measurements



©Frank van Diggelen, Google

With 3D maps



©Cyril Meurie, Uni. Eiffel

With cameras

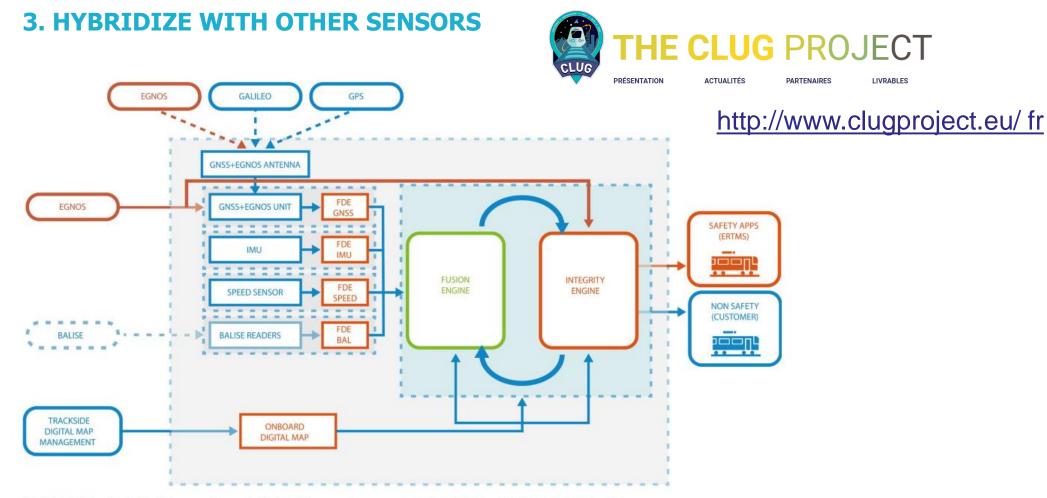


With ML



With FDE, RAIM





* EGNOS v3 DFMC service : EGNOS service on L1/L5 GPS, E1/E5 GALILEO



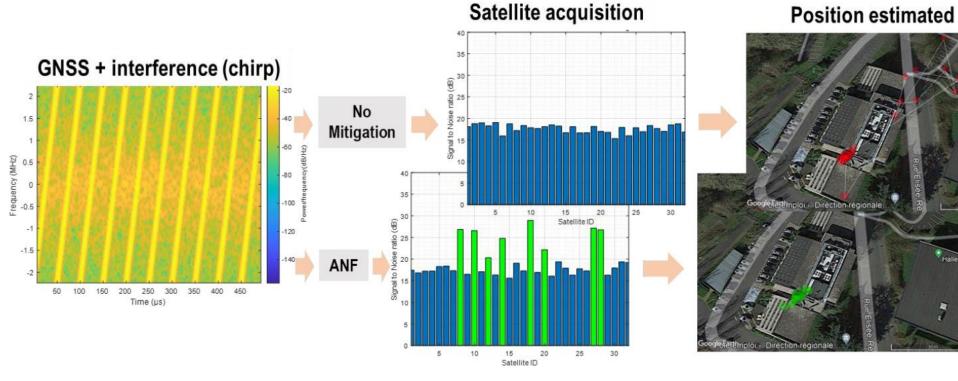
4. CHARACTERIZE UNCERTAINTY – THE CONCEPT OF INTEGRITY



In short: what is difficult? → Protection level computation (modelling errors)



5. MITIGATE INTERFERENCES





Juliette Marais, Syed Ali Kazim, Zaynab El Mawas, Maan El Badaoui El Najjar, Jeremy Skelton, Contributions to the development of safe and accurate localisation solutions: The LOCSP project, Accepted to TRA 2022, Lisbon

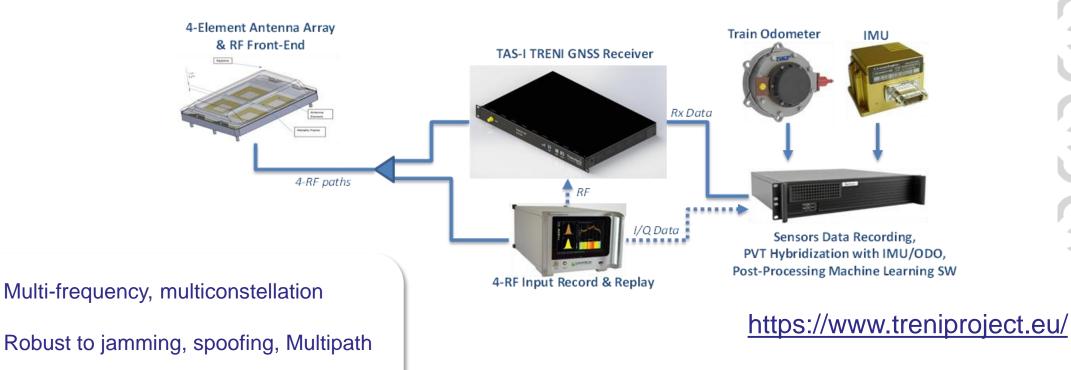


DEVELOPMENT OR A SPECIFIC GNSS RECEIVER FOR RAIL



Answering Railway safety standards

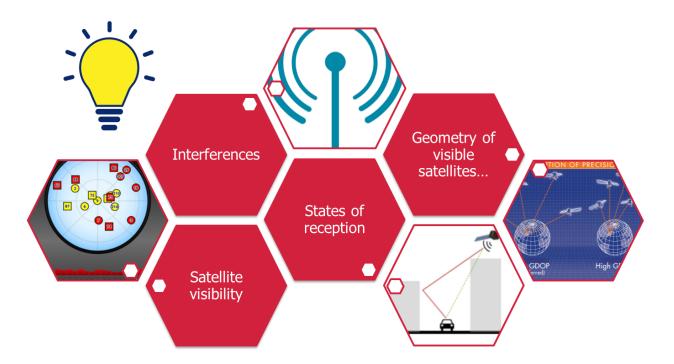
×. × (Train REceiver for Navigation and Integrity) A solution at Technology Readiness Level 7 (TRL7) providing PVT that will fulfill the accuracy and robustness requirements of several rail applications.







WE NEED TO QUANTIFY PERFORMANCE OF NEW SOLUTIONS

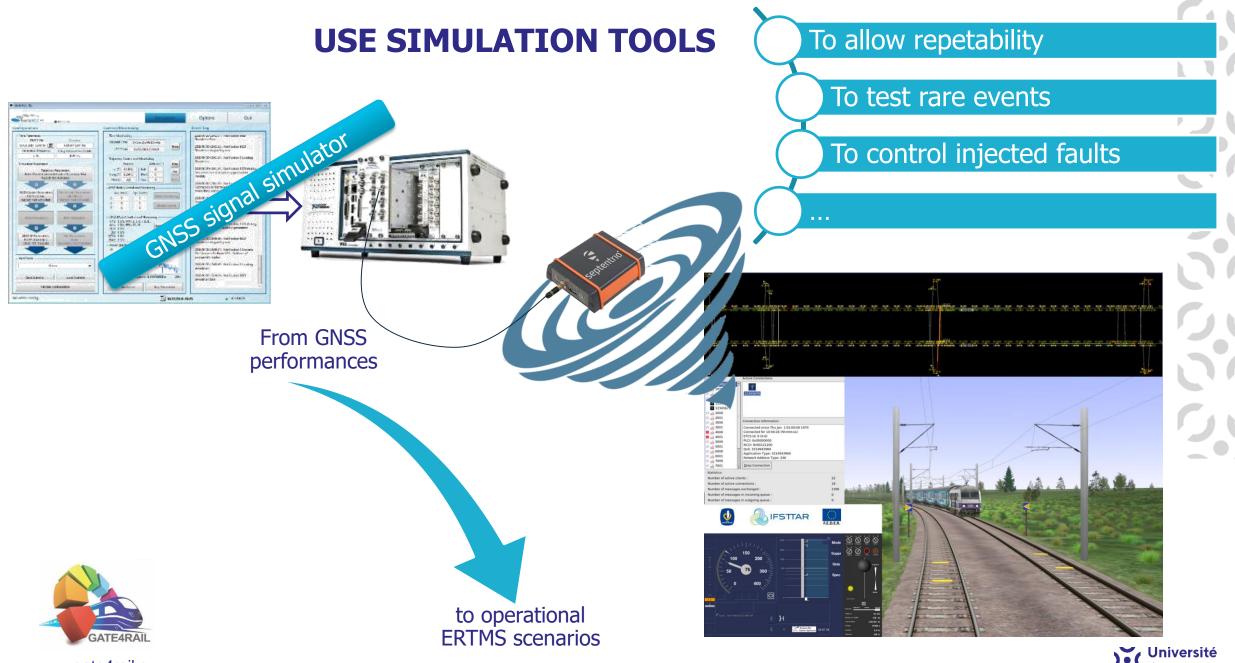












www.gate4rail.eu

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HOW TO RELY ON SIMULATION TOOLS?

- Check similarities
- What layer?

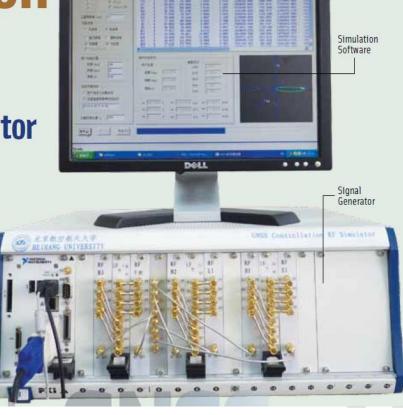


tors



Real data Simulation

Good



A need to develop testbeds, certified labs



QUANTIFY WITH MEASUREMENTS





RAILGAP

https://railgap.eu/

- 1. development of innovative and advanced methodology and related tools for designing accurate and reliable references (i.e. a Ground Truth for position and odometer information such as travelled distance, speed as well as accelerations and heading)
- 2. The definition of high integrity and accuracy ground truth and digital trackside map with integrity requirements



TOWARDS CERTIFICATION OPEN POINTS?

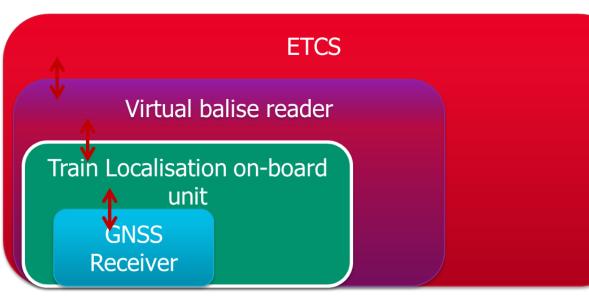
HOW TO CONSIDER GNSS-BASED SOLUTION IN A CERTIFICATION CONTEXT?

"A certifiable product in a railway system suitable for use as a component of a SIL4 system" (CLUG)

There are not yet requirements included in the TSIs for GNSS positioning unit or locator, but there will be in the future (TSI 2027?).

Functional performances and RAMS requirements shall be defined. Different options:

What will be the



SIL1-SIL2 (TRENI) SIL4 (CLUG)



SIL4

Université

From performance evaluation to safety report

Some remaining challenges





GNSS/multisensor hybridization is not yet defined/chosen



How to perform complete, quantifiable simulation and test fields?



Cai, B., Wu, B., & Lu, D. (2020). Survey of Performance Evaluation Standardization and Research Methods on GNSS-Based Localization for Railways. *Chinese Journal of Electronics*, *29*(1), 22-33.

Relevant safety demonstration tools?

- Traditional methods (FTA, FMEA) depend on system architecture
- Field tests are costly, time consuming and environment dependent
- Formal verification methods model the behaviour of the solution



Himrane, O., Beugin, J., & Ghazel, M. (2020, November). Towards a model-based safety assessment of railway operation using GNSS localization. In ESREL 2020 PSAM 15, 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference (p. 8p).



CONCLUSIONS

Now you know how your « magic » GNSS receiver works and how your smartphone knows every of your movements!

Now you know what you can expect (or not!) from it!

In good progress: Development of solutions that can reach requirements in terms of accuracy, availability, ...safety



Reliability, Safety and Security of Railway Systems

The next big challenge?







Juliette Marais

juliette.marais@univ-eiffel.fr Université Gustave Eiffel, Campus de Lille

