NLS
FINNISH GEOSPATIAL
RESEARCH INSTITUTE
FGI

FGI research on resilient Positioning, Navigation, and Timing (PNT)

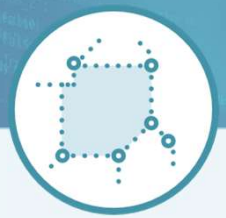
EuroSDR Workshop

Beyond GNSS: resilient positioning and aerial mapping

Sanna Kaasalainen

Professor, director: Navigation and positioning

Contents

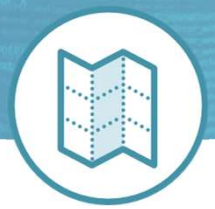


Global Navigation Satellite Systems (GNSS)

Critical infrastructures

GNSS interference in Eastern Finland

Interference detection



Towards resilient positioning

Galileo’s new services

Alternative PNT methods

Future navigation

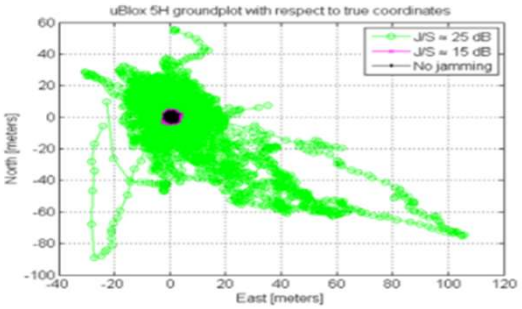
Summary: how to get resilient **Positioning, Navigation, and Timing (PNT)**

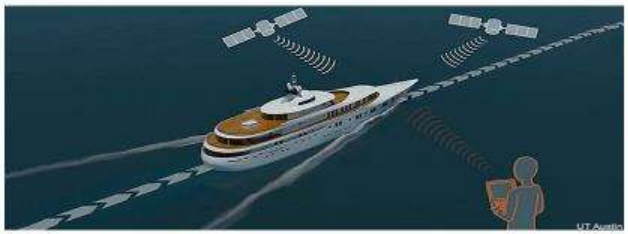
Satellite positioning and critical infrastructure

Global Navigation Satellite Systems (GNSS)

	GPS	GLONASS	Galileo	BeiDou (BDS)
Owner	USA (US Space Force)	Russia (Roscosmos)	**EU (EUSPA)**	China (CNSA)
Status	Operational (31 sats in orbit), modernisation ongoing (GPS III)	Operational (24), modernisation ongoing	**Initial operational capability (31/27) Fully operational Q4/2025 (L14)**	Full operational capability (45 sats)
Erityistä	Limited civil usage	Better coverage at high latitudes (affects accuracy)	**The only civilian GNSS**	Also contains geostationary satellites

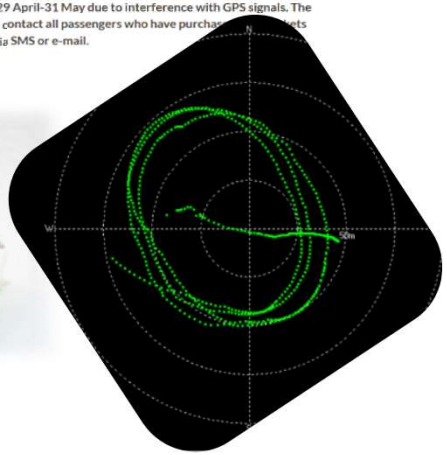
GNSS jamming and spoofing

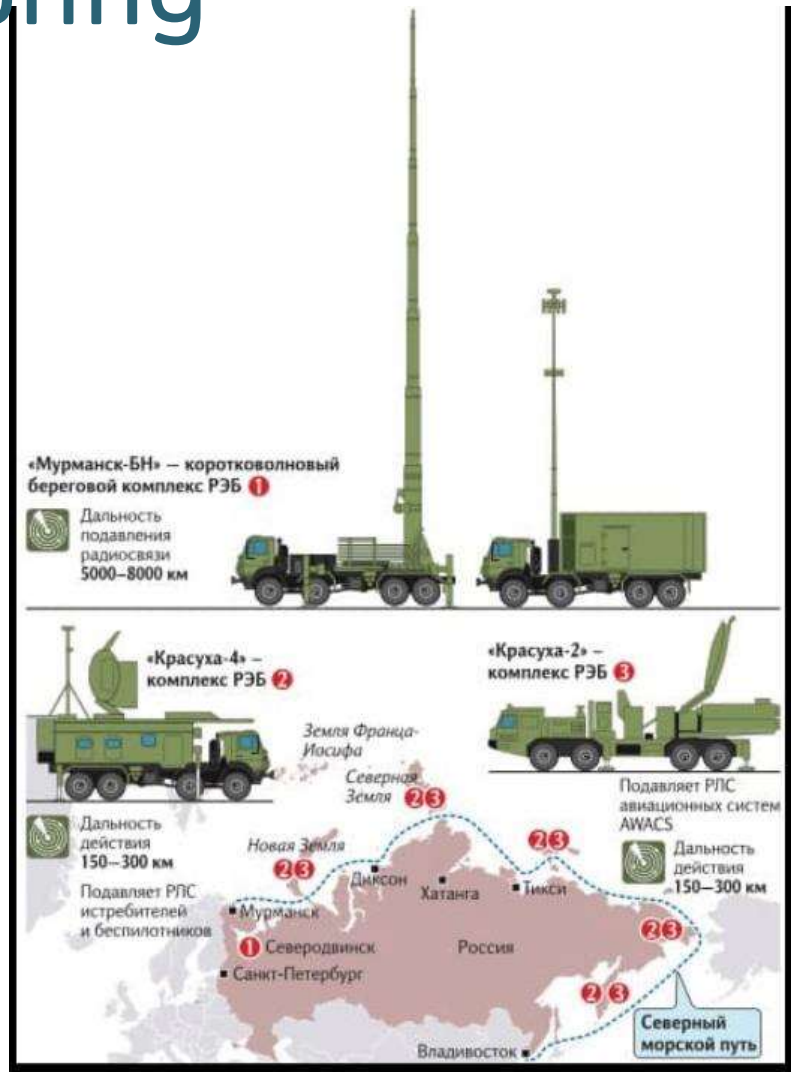




Yacht hijacking shows the potential power of GPS spoofing

By Kevin McCaney Aug 01, 2013





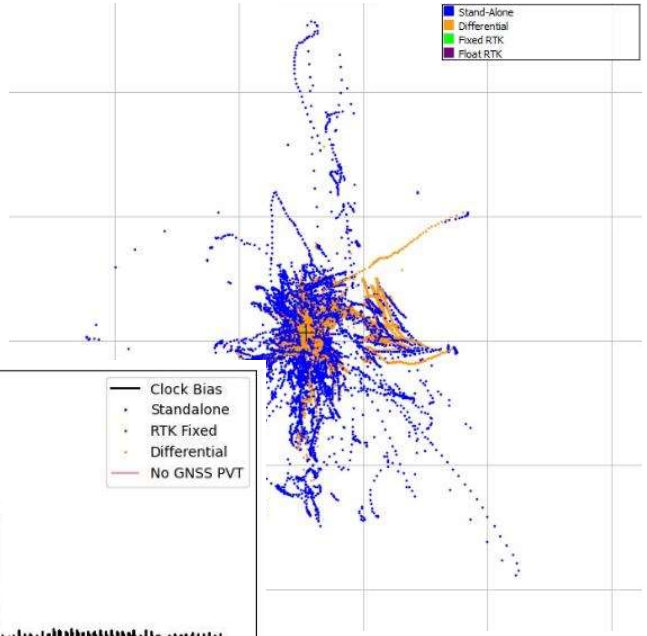
Effect of interference on GNSS receivers

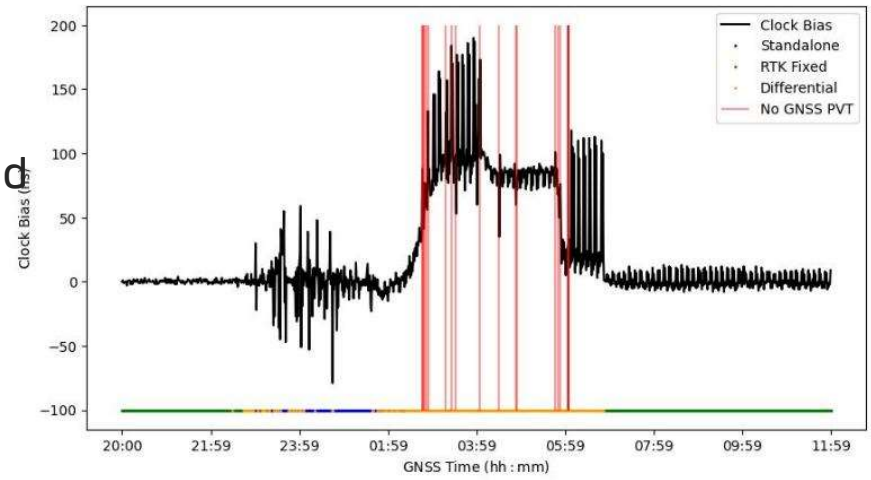
Example case:

- Extended jamming attack against a modern Multi-frequency, Multi-constellation GNSS receiver
  - All available constellations: Galileo, GPS, Glonass, BeiDou
  - All available signals

- Jamming targeting upper L-band
  - L1,E1,B1,G1

- Positioning is possible at lower L-band
  - E5, L5, B3, G2

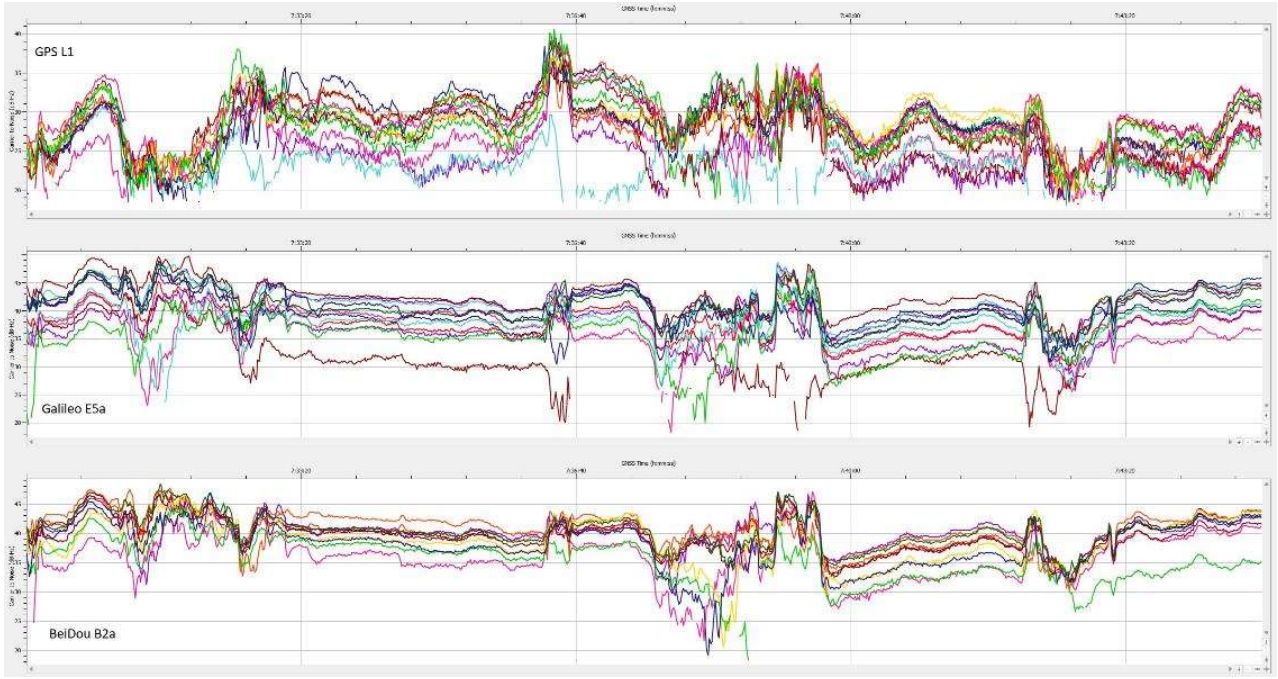


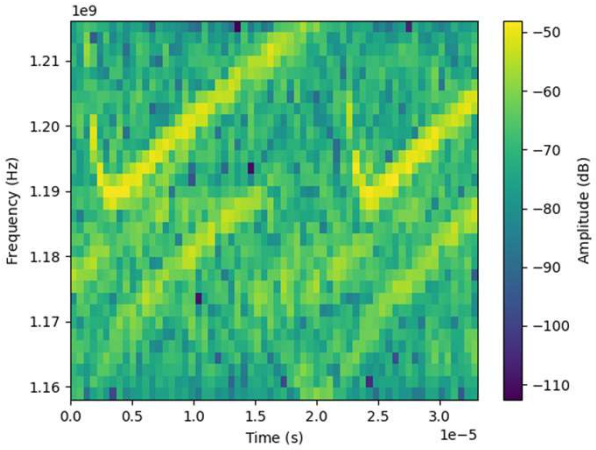


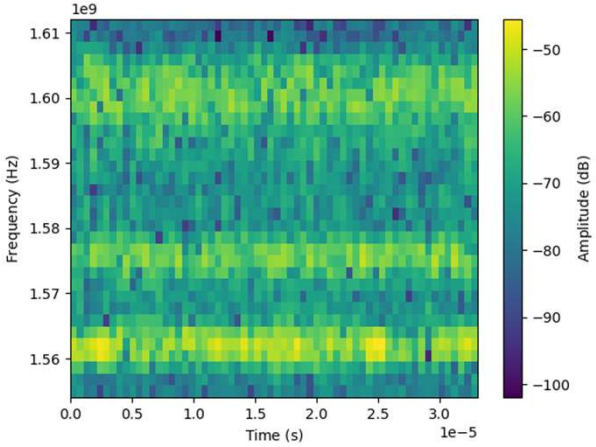
Effects:

- Positioning accuracy degraded
  - From cm-level → ~10 m
- Time synchronisation
  - Clock bias increased by up to 180 ns

NLS imaging flights 2025



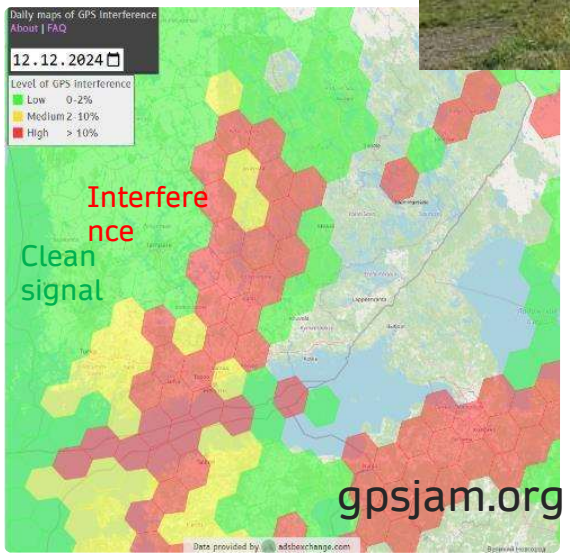




GNSS jamming in Eastern Finland

- Severe interference since 2024
- High impact on air traffic
- NLS-FGI continues R&D in GNSS jamming resistance
  - Interference detection in airships funded by Regional Development Fund
  - Collaboration with Eastern Finland companies
- 2025: testing new equipment during NLS's flight campaigns + Jammertest Andøya, Norway

European Union
European Regional Development Fund

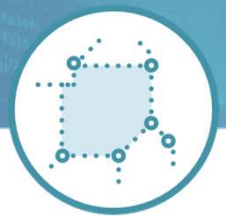


septentrio

KELLUU

Ministry of Agriculture and Forestry of Finland

Contents



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Galileo's new services

Open Service Navigation Message Authentication (OSNMA):

- FGI-OSNMA decoder library published 2023 at the ION GNSS+ conference, testing in Jammertest 2025 + Eastern Finland
- Helps make any receiver OSNMA capable

High Accuracy Service (HAS): precise positioning from space

- **High accuracy corrections directly from space, allowing 10-20cm accuracy and making GALILEO the most accurate GNSS**
- FGI-Navi's HAS decoder library (https://github.com/nlsfi/HASlib) published 2022 and tested for different applications:
  - Fall 2023 Galileo HAS in a forest harvester
  - Testing Galileo HAS in NLS production, 2025 Jammertest

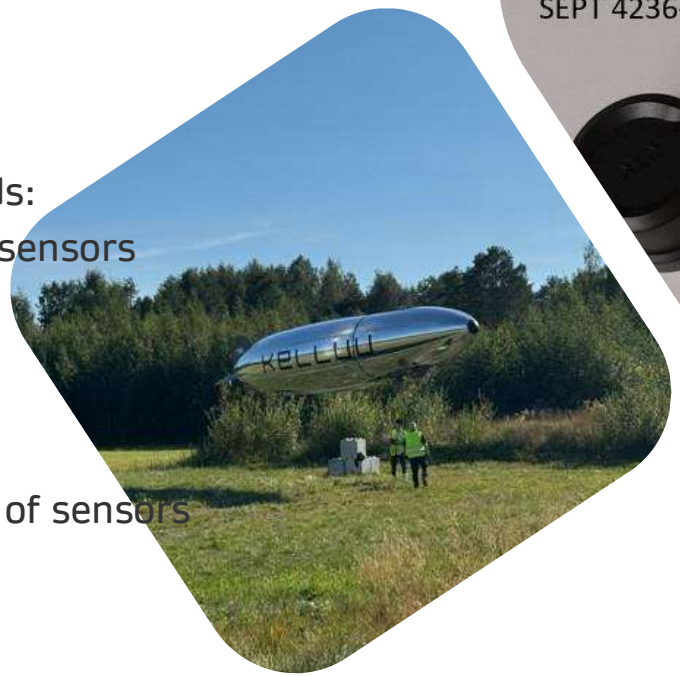
Public Regulated Service (PRS): IOC 2025

- FGI helps Traficom in utilizing PRS in Finland

FGI-OSNMA-library available here:

FGI’s resilient PNT concept

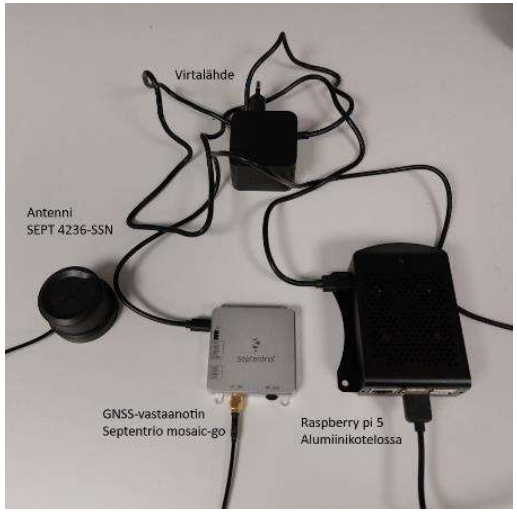
1. Real-time identification and jamming resistance:
   A. Signal integrity monitoring, extended test scenarios and live testing
   B. Classification + localization of jamming sources to activate mitigation methods
   C. FGI-OSNMA for spoofing detection
   D. Optimizing receivers and antennas
2. Implementing alternative navigation methods:
   A. Collaborative positioning from multiple sensors (cameras, radio sensors, lidar)
   B. Signals-of-opportunity
3. Helping users to customize the solution:
   A. Improved situational awareness
   B. Collaborative networking and operation of sensors

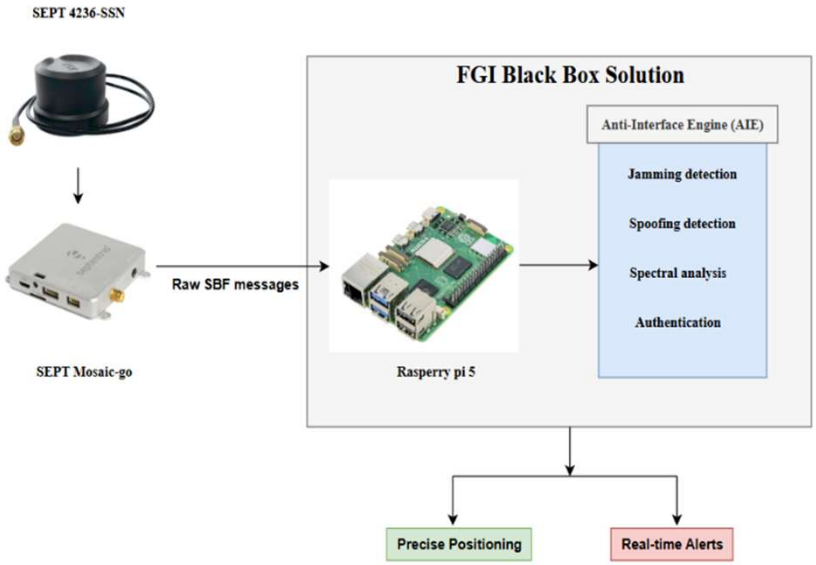


FGI-Shield

- Hardware:
  - 1x antenna
  - 1x Receiver (Septentrio Mosaic-go)
  - 1x Raspberry-Pi
    (as computational engine)

- Anti-Interference Engine
  - Real-time interference detection + mitigation
  - Integrity monitoring
  - Situational awareness





Jammertest: Andøya, Norway 2025

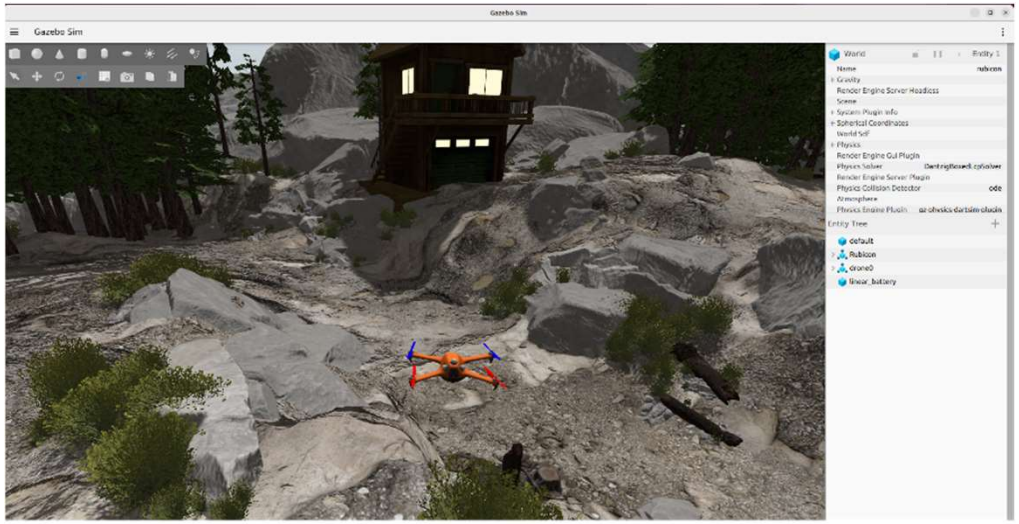
FGI in Jammertest:

- Testing the effects of jamming/spoofing on GNSS reference stations
- Galileo authentication and receiver testing
- **2025: testing the FGI-Shield + hybrid positioning systems**

https://jammertest.no/

GNSS is not enough

- **FGI participates in European Space Agency's (ESA) navigation program:**
  - GNSS and optical sensors for drone positioning
  - Precision Agriculture Alignment Instrument; tractor positioning
- **Hybrid positioning for agriculture + drones**
  - 1 cm accuracy needed in agriculture
  - Navigation + situational awareness
- **Add sensors for better reliability**
  - Need to identify reliable data sources → Integrity monitoring



Agriculture needs precise positioning

- Accuracy requirements down to cm-level
    - Via high-performance GNSS
  - Transportation & machinery automation
    - Machinery with articulated joints
- For multi-joint systems
  - E.g. robot fruit picking
    - GNSS becomes expensive and cumbersome
      - Joint sensoring (mechanical) is also problematic

⇒ Large potential in articulated machinery positioning

⇒ Needed for automation

How to improve positioning with sensors?

Design

Preliminary testing of (existing) sensors:

- Rough assessment of robustness, accuracy
  - Stereocamera, Time-of-flight camera, thermal camera, lidar
- Evaluation of SLAM against dust conditions using publicly available material

Sensor testing

Use cameras to get the trailer position relative to tractor

First results: 1 cm relative positioning accuracy

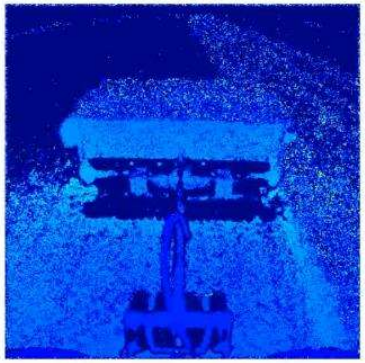
Stereo pair: left

Stereo pair: right

Thermal

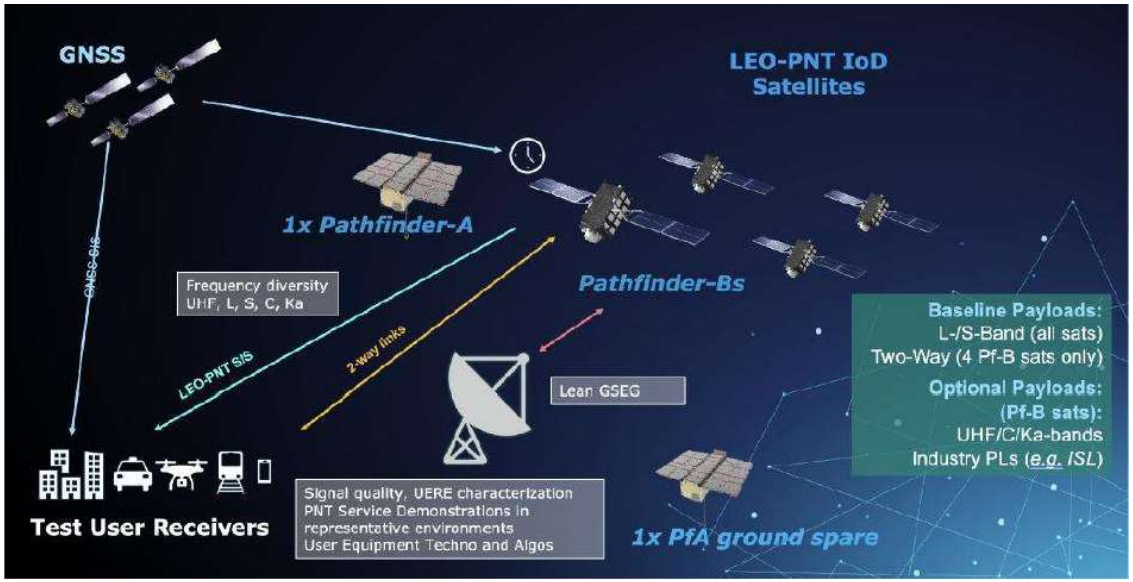
ToF image

ToF radial depth



LEO-PNT in-orbit demonstration 2025

LEO = Low-Earth-Orbit
A new satnav layer to complement the European Galileo constellation for added resilience and novel services



A Low Earth Orbit constellation dedicated to Positioning Navigation and Timing

A game changer for increased precision, resilience and signal penetration enabling new applications and economic growth

esa leo–pnt

NLS NATIONAL LAND SURVEY OF FINLAND

ThalesAlenia Space
a Thales / Leonardo company

European LEO-PNT Solution

Characteristics of LEO satellite constellations

- ⇒ Larger constellations with rapid revisit times
- ⇒ Faster speed and lower latency
- ⇒ Multi-beam transmission possibility
- ⇒ **Resilience and robustness in PNT service**
  - ⇒ Higher signal strength and lower proximity
  - ⇒ Handful options from a variety of players:
    - ⇒ **Frequency diversity: UHF, L, S, C bands**
      - ⇒ GNSS-like signal characteristics at L & S bands
    - ⇒ **Both private and public service providers**
    - ⇒ Faster response to interference
- ⇒ **A hacker would need to wipe out a wide range of frequencies with high transmission power for a complete GNSS-like disruption**

Key systems and initiatives: Xona, Centispace, TrustPoint, FutureNAV, etc.

Source: INCUBATE project
https://www.incubateproject.org

INCUBATE

Aalto University

Vaasan yliopisto
UNIVERSITY OF VAASA

Tampere University
Tampere University of Applied Sciences

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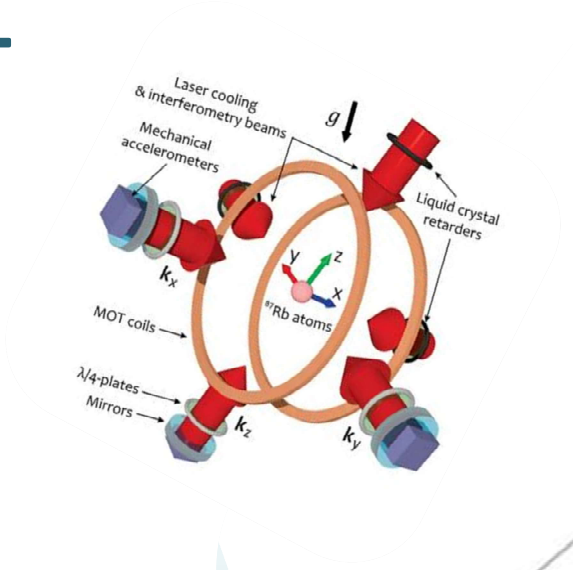
Future trends for PNT

- GNSS still an excellent system!
  - Easy to use
  - Cost efficient
  - Precise
- Authentication services
  - Galileo OSNMA
  - Galileo PRS
  - Chimera (GPS L1 authentication)
- But what if GNSS is unavailable?
- Sensor fusion and system of system approach
- Low Earth Orbit (LEO) constellations
  - Dedicated PNT system
  - supporting GNSS
- Quantum navigation



Templier et al, Science Advances (2022)

Image credit: Edge.auto

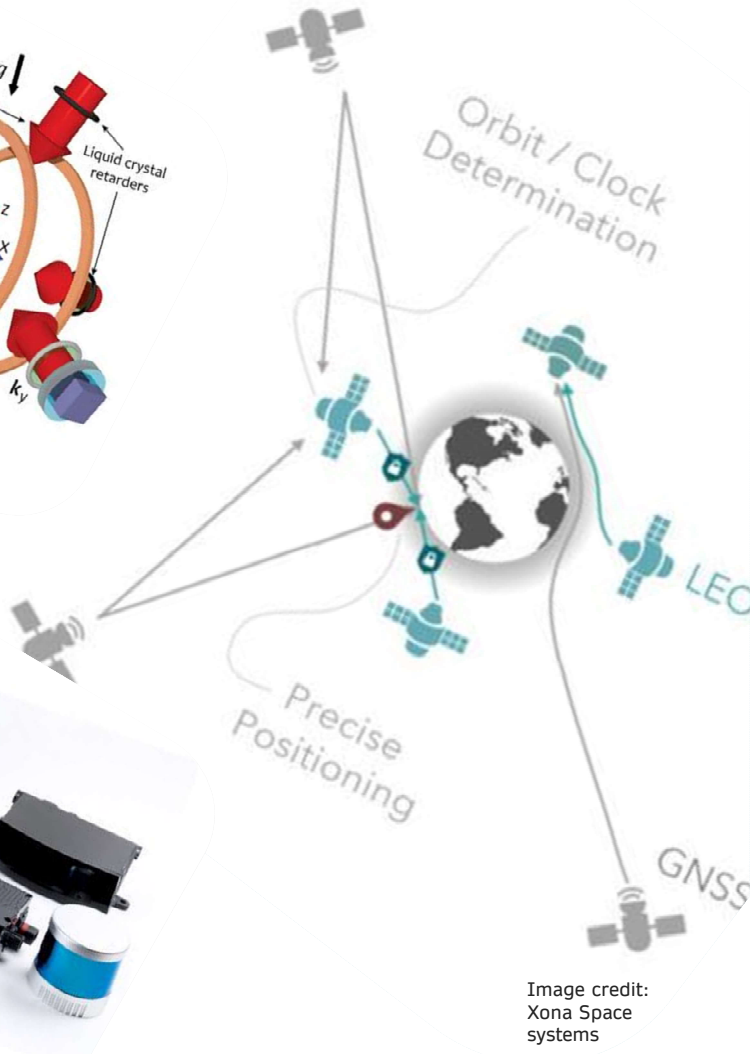
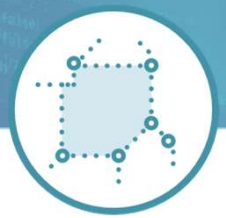


Image credit: Xona Space systems

Contents



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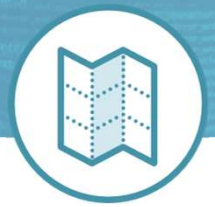

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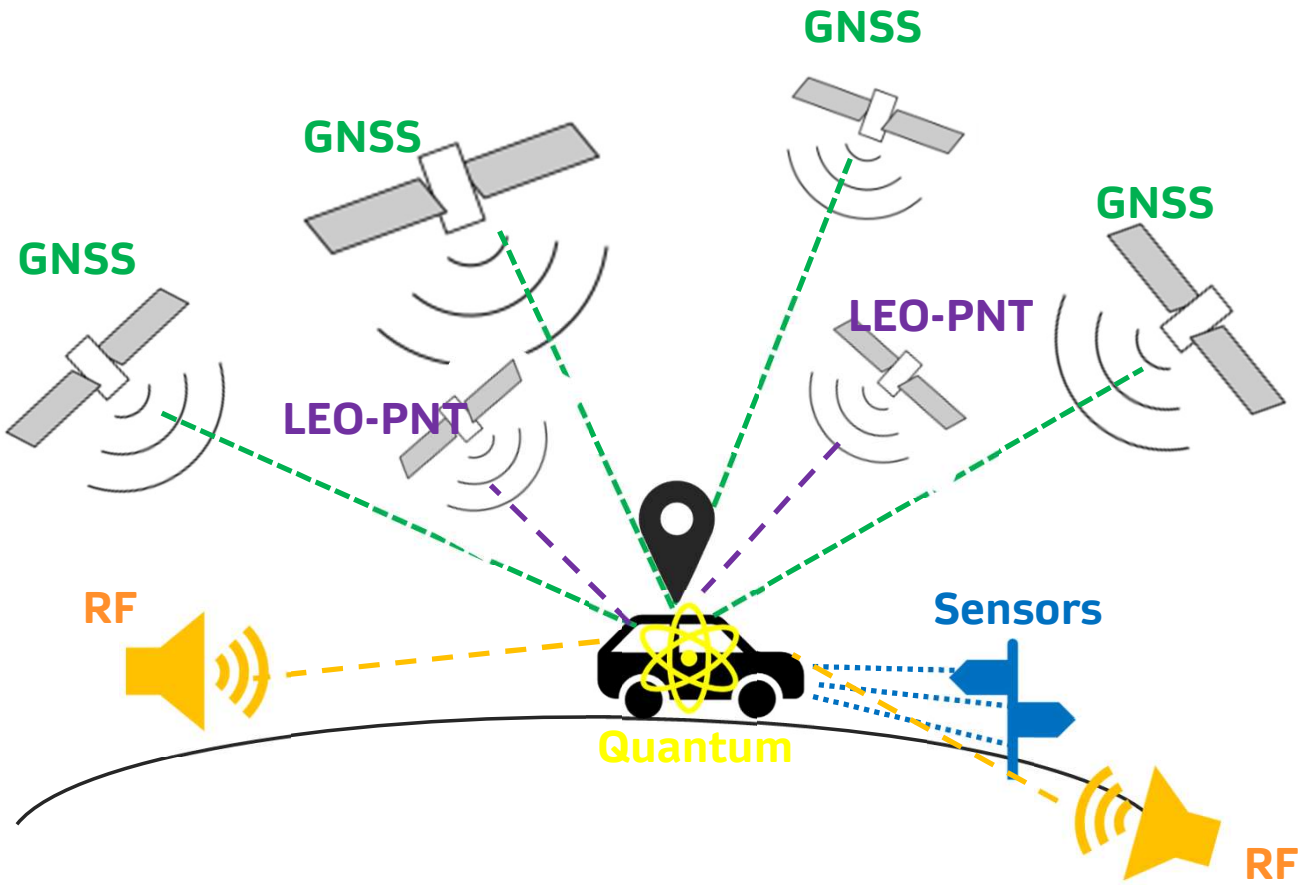
Resilient PNT



GNSS: multi-frequency, multi-constellation

LEO-PNT: independent and interoperable with GNSS

Sensors and collaborative navigation

Radio Frequency navigation (eLoran, signals of opportunity)

Quantum navigation with quantum sensors

Thank you!

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