Complementing GNSS for Resilient Performance Based Navigation

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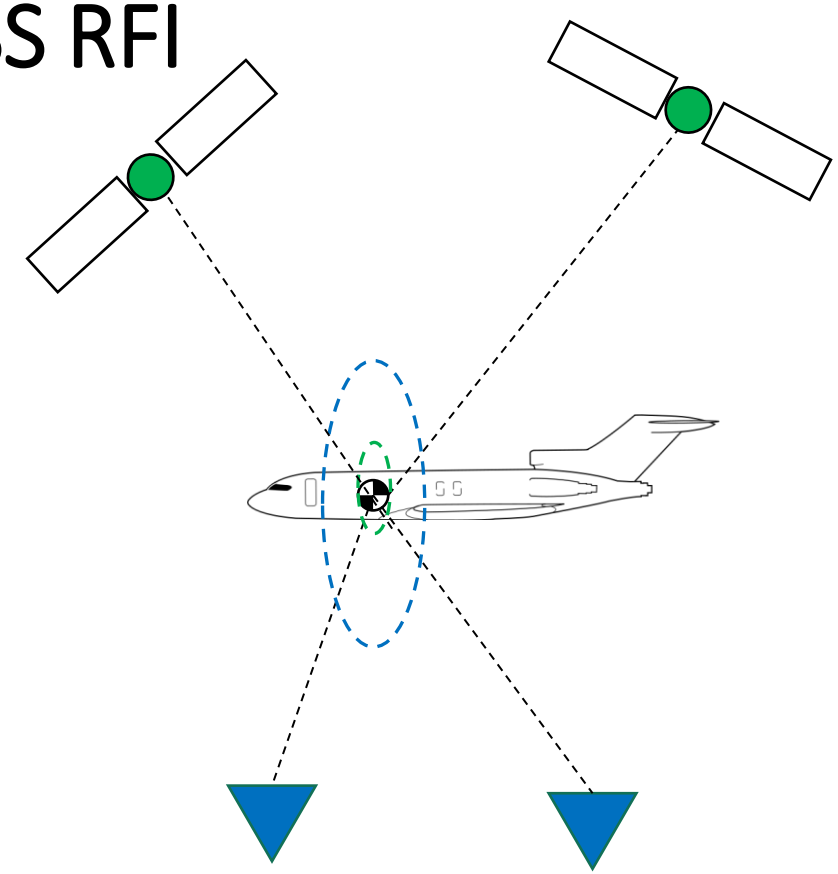
Goal: PNT availability, regardless of GNSS RFI

(Well) integrated terrestrial Complementary PNT sources:

- Provide alternative/backup to GNSS:
  - Seamless positioning (even under RFI)
  - Timing
  - Continuity of PBN/RNP
  - Dissimilar cross-check of GNSS (anti-spoof)
- May provide Data COM:
  - GNSS Differential Corrections
  - GNSS Authentication



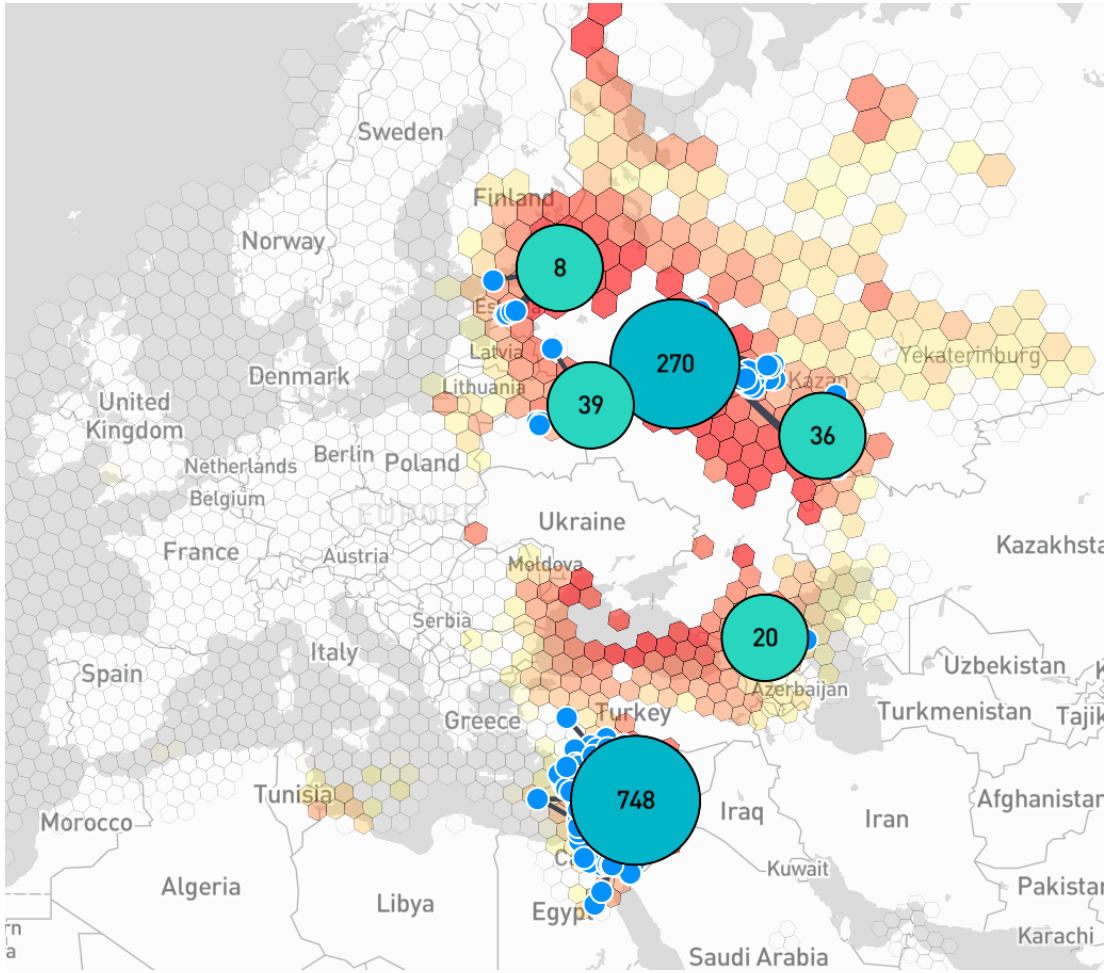
Osechas, et al. (2017), “Use of APNT to Protect GNSS-Based RNP Services from Intentional and Unintentional RF Interference”. ION ITM 2017.

Complementary PNT is more than a backup to GNSS (1+1>2 !)

Outline

- Effect of RFI on aviation
- Performance Based Navigation (PBN) Overview
  - Importance of PBN to modern aviation
  - Reliance of PBN/RNP on GNSS
- Complementary PNT (CPNT) technologies for achieving resilient PBN
  - Legacy navigation aids
  - Modernized terrestrial radio navigation
  - LEO PNT, 5G
- Resilient CPNT technology assessment
  - Overview of candidate systems
  - Set of performance criteria
- Recommendations

GNSS jamming and spoofing are hindering enroute air traffic



Skai Data Services / ZHAW

- Jamming: worldwide and increasing
- Spoofing: is now a daily occurrence
- Aviation is a collateral victim

Operations comply with safety standards, but RFI reduces margins

Osechas, et al. (2022), "Impact of GNSS-Band Radio Interference on Operational Avionics". NAVI Vol. 69, Issue 2 Summer 2022.

OPSGROUP (2024), "GPS Spoofing, Final Report of the GPS Spoofing WorkGroup", https://ops.group/blog/gps-spoofing-final-report/.

Threats to GNSS

- Jamming
- Spoofing

} RFI

- Space weather – Iono scintillation

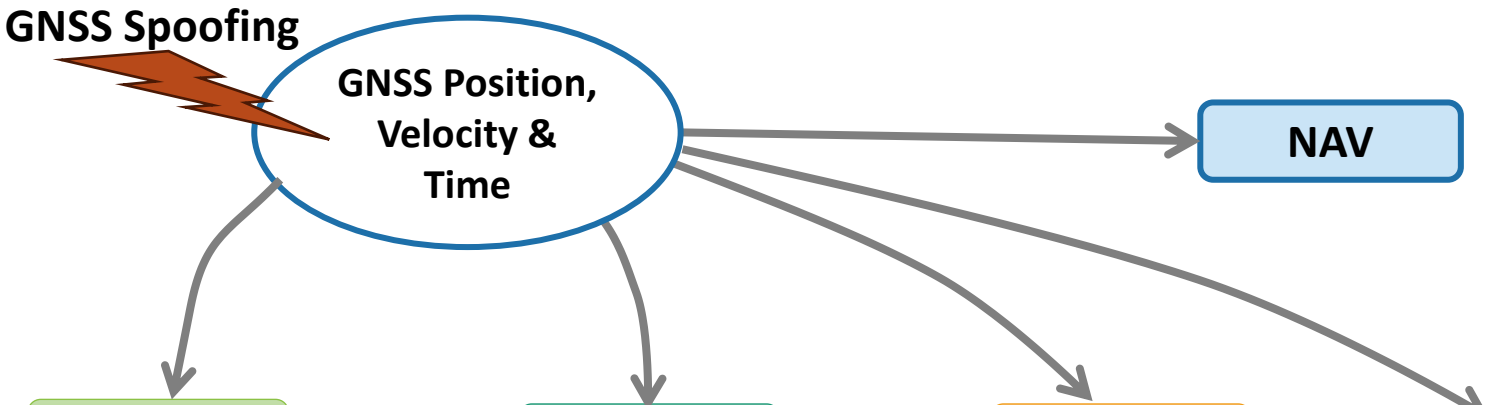
- Degraded SiS : DoS + HMI
- Users can mitigate
- **Benefit from other PNT sources**

- Space weather – HW damage
- Space debris
- Anti-satellite weapons
- Cyber attacks

- Loss of SiS
- Users cannot mitigate
- **Require other PNT sources**

Complementary PNT needed!

GNSS spoofing induces multiple issues for aviation



- Degraded or loss of GNSS PVT
- Erroneous GNSS PVT
- Loss of RNP/RNAV
- Unintended airspace incursions
- Unreliable IRS
- Loss of automated DME/VOR tuning

- Discarded CPDLC messages
- Weather uplink
- Automatic VHF / SATCOM tuning

- Loss of or misleading:
  - TAWS
  - ADS-B,-C
  - ACAS
- Degraded WXR processing

- Degraded AHRS
- Loss of or misleading:
  - HUD
  - SVS
  - FMS functions

- Loss of or misleading:
  - Date / time
  - Fuel consumption

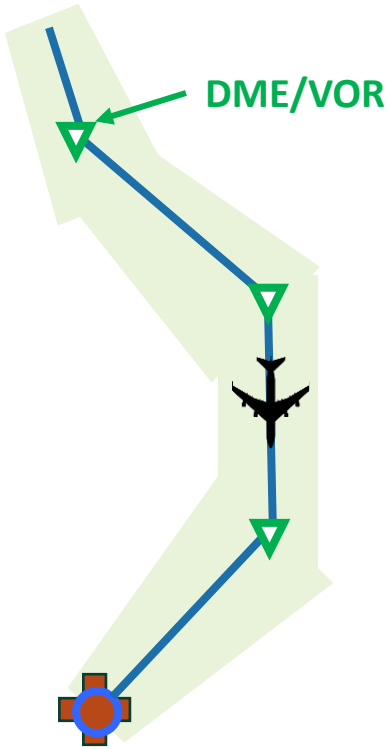
Unexpected dependencies on GNSS
➔Deficiencies in system integration!

OPSGROUP (2024), "GPS Spoofing, Final Report of the GPS Spoofing WorkGroup", https://ops.group/blog/gps-spoofing-final-report/.

EASA (2024), "Safety Information Bulletin 2022-02R3: Global Navigation Satellite System Outage and Alterations Leading to Communication / Navigation / Surveillance Degradation".

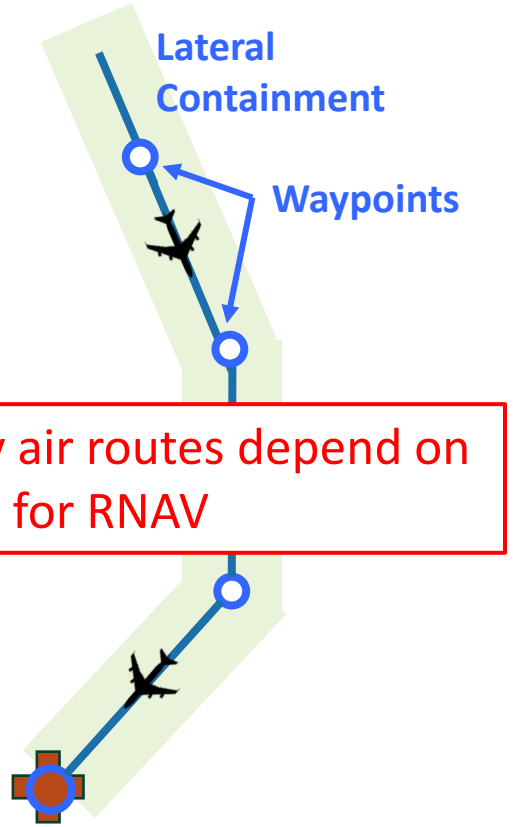
PBN yields efficiency, flexibility and increased capacity

Legacy NAVAID Routing



Fixed Routes

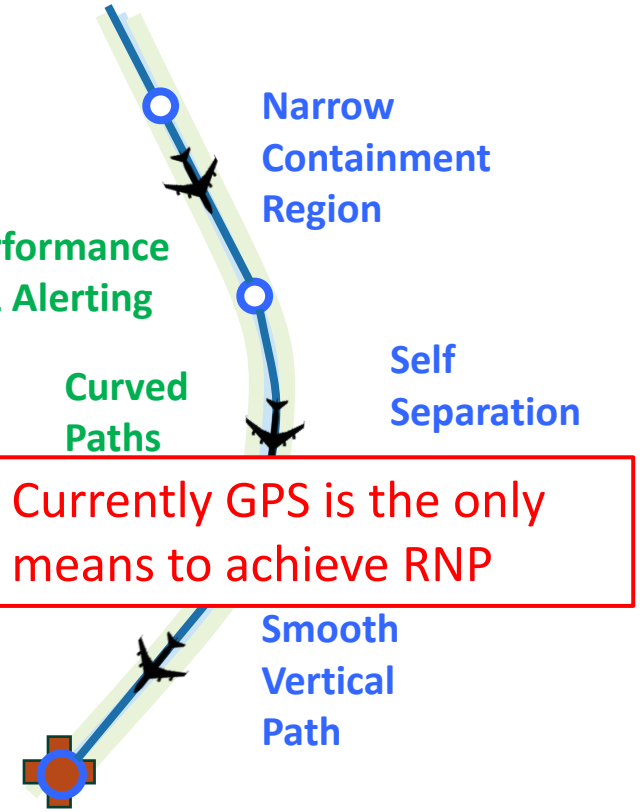
RNAV



Many air routes depend on GNSS for RNAV

Flexible Routes & increased capacity

RNP

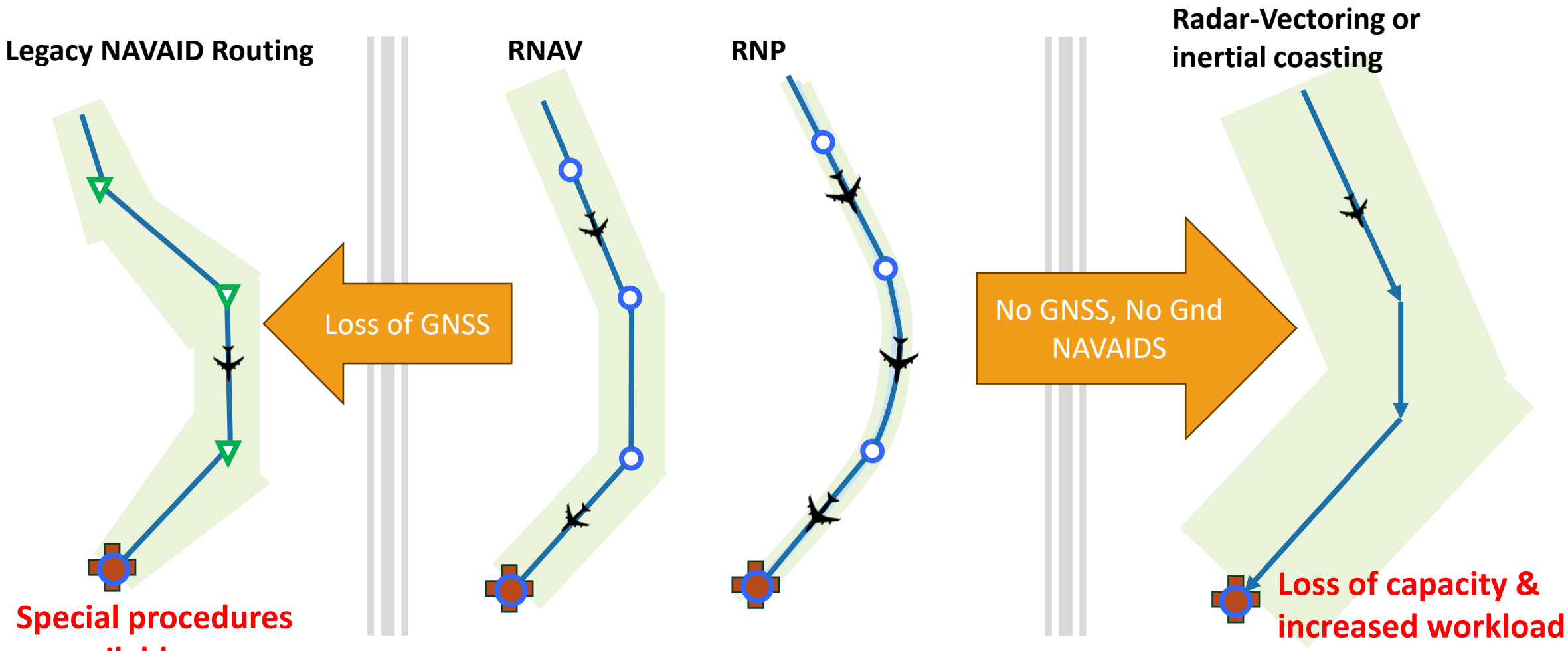


Currently GPS is the only means to achieve RNP

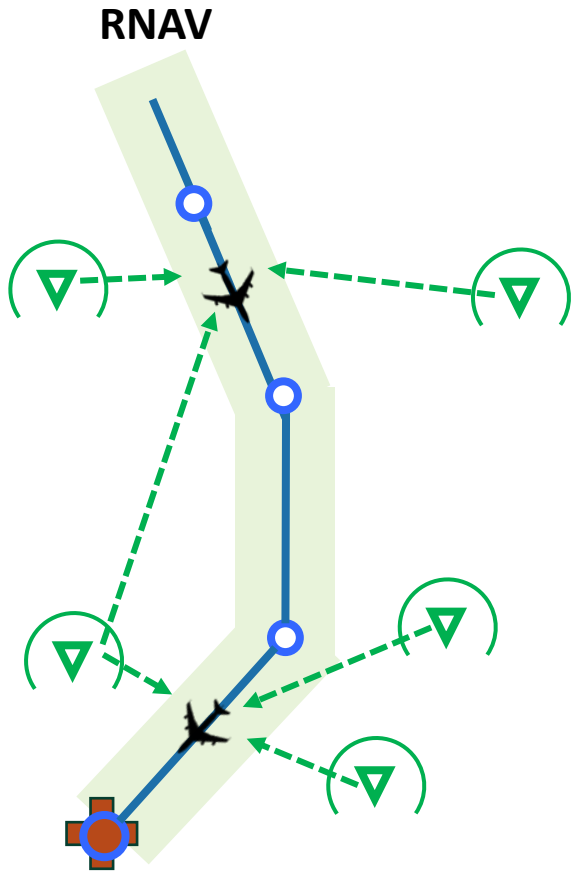
Optimized operations

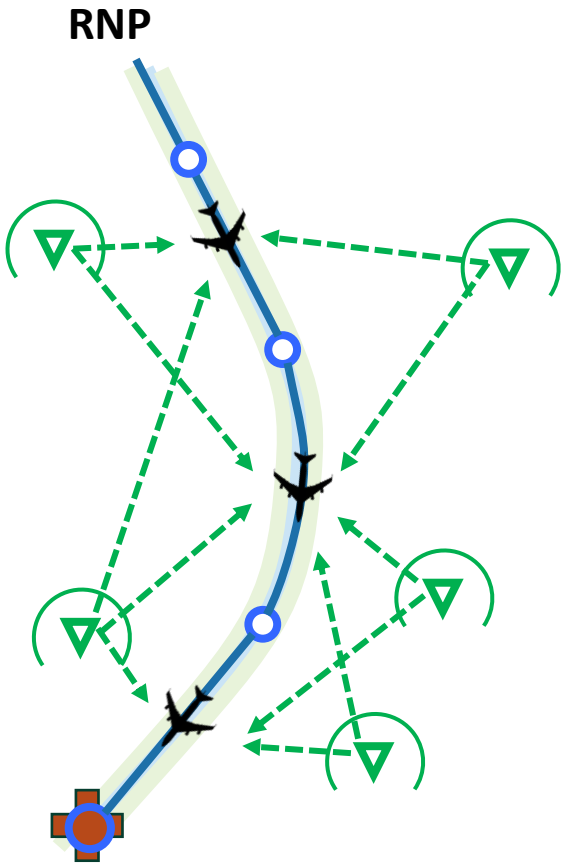
RNAV *x*: *x* NM 95% Total System Error
RNP *x*: *x* NM 95% Total System Error + On-Board Performance Monitoring & Alerting

Loss of GNSS disrupts operations



Need modernized CPNT to support RNP/RNAV





Need:

- Frequency diversity: non-GNSS ARNS
- Cross-check of GNSS: anti-spoof
- Robust integration of CPNT

To provide:

- Resilient RNP (e.g., OBPMA)
- Improve spectral efficiency (iCNS)
- Fill in RNAV CPNT gaps
- Support emerging aviation applications (e.g., AAM)
- Support autonomous operations

No single CPNT source can back up GNSS!

Osechas, et al. (2024), “Navigation Needs for the Unpiloted Airspace.” ION ITM 2024.

A priori list of potential Complementary PNT sources

Terrestrial

Existing Aviation Radio NAV

- VOR/DME
- DME/DME

Enhanced Aviation Radio NAV

- eDME
- eLORAN

Multi-Function COM

- LDACS
- 5G Commercial Cellular

Alt. Space

LEO SATNAV

- Existing, e.g. Iridium/STL
- Emerging, e.g., Starlink, Xona, Trustpoint

CPNT solution evaluation summary

	Operations Supported	Deployment	Operational Coverage	Backwards Compatibility	Spectrum Efficiency	Capacity Limits	Other Applications	Provides Timing	Authentication
DME/VOR	RNAV 5	Deployed / Certified	40 NM		High PAPR	Capacity Limited	Designed for Aviation		
DME/DME	RNAV 1	Deployed / Certified	200 NM		High PAPR	Capacity Limited	Designed for Aviation		
eDME	RNP 1	New Gnd / Air Equip.	200 NM	Yes: 100%	High PAPR	PR mode	Designed for Aviation	~100 ns	Possible
eLORAN	RNP 0.3	New Gnd / Air Equip.	~1000 NM	New Aero NAVAID	Not L-Band	Passive	Maritime & Timing	~100 ns	Possible
LDACS-NAV	< RNP 0.3	New Gnd / Air Equip.	200 NM	New Aviation COM	Shared with COM	PR mode	Potential for AAM	< 100 ns	Encrypted COM
5G Cellular	RNP 0.3?	New Paradigm	<40 NM	New System	Separate from ARNS	Capacity Limited	Potential for AAM, GND	?	Encrypted COM?
LEO SATNAV	?	New SVs / Air Equip.	?	New System	Separate from ARNS	Passive?	Land/Sea/Air	< 100 ns	?

Poor/Costly | Marginal | Fair | Good | Excellent | N/A | Can't Evaluate

CPNT solution evaluation discussion (1)

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eLOR	< RNP 0.3	New Gnd / Air Equip.	200 NM	New NAVAID	Shared L-Band	PR mode	Potential for Timing	< 100 ns	Encrypted
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LEO SATNAV	?	New SVs / Air Equip.	?	New System	Separate from ARNS	Passive?	Land/Sea/Air	< 100 ns	?

- Legacy NAVAIDs do not support PBN needs – want RNP-APCH/RNP 0.3 or better
- Modernization is needed!

CPNT solution evaluation discussion (2)

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LEO SATNAV	?	New SVs / Air Equip.	?	New System	Separate from ARNS	Passive?	Land/Sea/Air	< 100 ns	?

- 5G Cellular & LEO SATNAV as aviation CPNT sources are not well defined
- Unlikely to provide performance guarantees that civil aviation users expect
- May have promise for emerging applications like AAM, UAS

CPNT solution evaluation discussion (3)

- eDME, eLORAN and multi-function COM (LDACS-NAV) show the most promise

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LDACS-NAV	< RNP 0.3	New Gnd / Air Equip.	200 NM	New Aviation COM	Shared with COM	PR mode	Potential for AAM	< 100 ns	Encrypted COM

Candidate terrestrial navaids for CPNT

- Near-term: eDME
  - ✓ Backwards compatible: add local oscillator and pseudoranging
  - ✘ Lower RNP, spectrum efficiency (high PAPR in L band)
- Medium-term: eLORAN
  - ✓ Remote routes (think Eastern Med!); wide-area time distribution
  - ✘ Significant new infrastructure; new standards needed
- Medium- to Long-term: LDACS-NAV
  - ✓ Lower RNP; spectrum efficiency; ICAO standardization in process
  - ✘ Significant new infrastructure

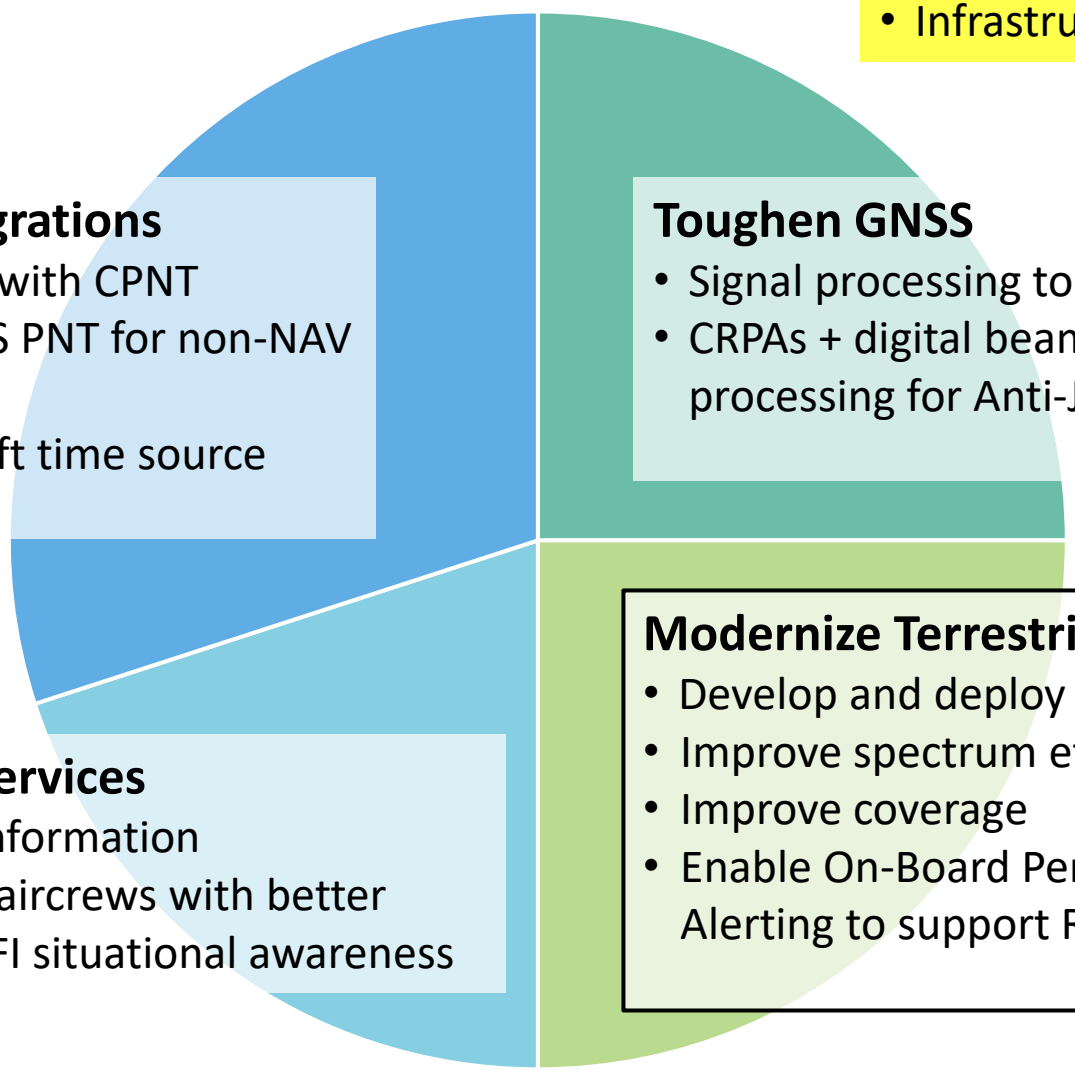
A combination of CPNT technologies will be needed

High-level recommendations

Foster Collaboration
- International coordinated R&D
- Expedite standards developments
- Infrastructure investments

Improve Aircraft PNT Integrations
- Robust monitoring of GNSS with CPNT
- Eliminate direct use of GNSS PNT for non-NAV functions
- Have an independent aircraft time source

Toughen GNSS
- Signal processing to detect & exclude spoofing
- CRPAs + digital beamforming antenna signal processing for Anti-Jam / Anti-Spoof



Improved Air Traffic Services
- Bring in real-time RFI information
- Provide operators and aircrews with better preflight & real-time RFI situational awareness

Modernize Terrestrial Complementary PNT
- Develop and deploy new CPNT sources
- Improve spectrum efficiency
- Improve coverage
- Enable On-Board Performance Monitoring & Alerting to support RNP operations

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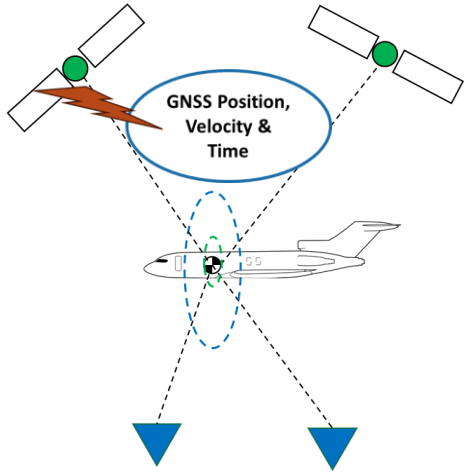
RESILIENT NAVIGATION and TIMING FOUNDATION
Speaking Up for GPS/GNSS Users

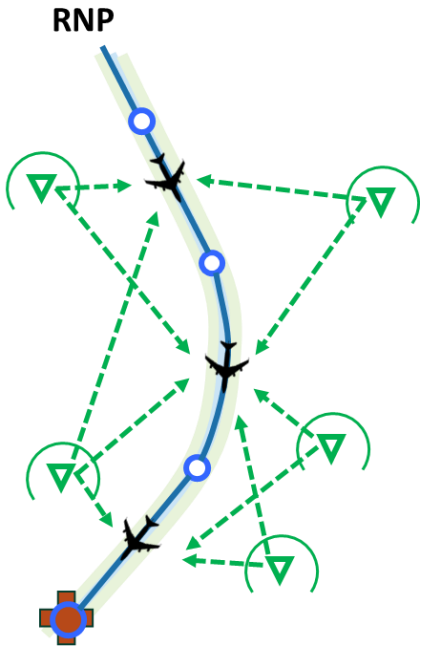
Summary

- RFI is a serious threat to aviation
  - Reduction of safety margins
- Preserve RNP in absence of GNSS

➔Develop terrestrial CPNT for RNP

  - eDME
  - eLORAN
  - LDACS-NAV
- Paradigm shifts:
  - Improve integration
  - Remove unnecessary dependence on GNSS
  - Terrestrial no longer “Alternative”
    Needs to be a full “Complementary”
  - Consider multi-domain solutions to go beyond just aviation
- Continue (funding) research and development
  - Multi-function radio links
  - Technologies to support AAM/UAS
  - More international collaboration!





Thank you for your attention!
osec@zhaw.ch

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