GNSS Interference Monitoring from Space

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RFI-LEOM Project.

- The **RFI-LEOM Project** designs a GNSS spectrum monitoring-system, for Galileo open service signals and other GNSS signals, based on space-borne monitors at LEO orbit, enabling detection, characterization & localization of ground-based interferers over very wide areas. It is an ESA Phase 0 exploratory study, which does not convey any programmatic decision

RFI-LEOM Project.

- Flight experiments by means of radio-occultation GNSS receiver on board the International Space Station performed by U.S. Naval Research Laboratory, have demonstrated monitor feasibility *(“Serendipitous Observations of GPS. Interference by GROUP-C on the ISS”)* .

- The Project has closed the System Requirements Review (SRR) and is approaching its Preliminary Design Review (PDR).

Techniques for Monitoring and Localisation

Monitoring Techniques.

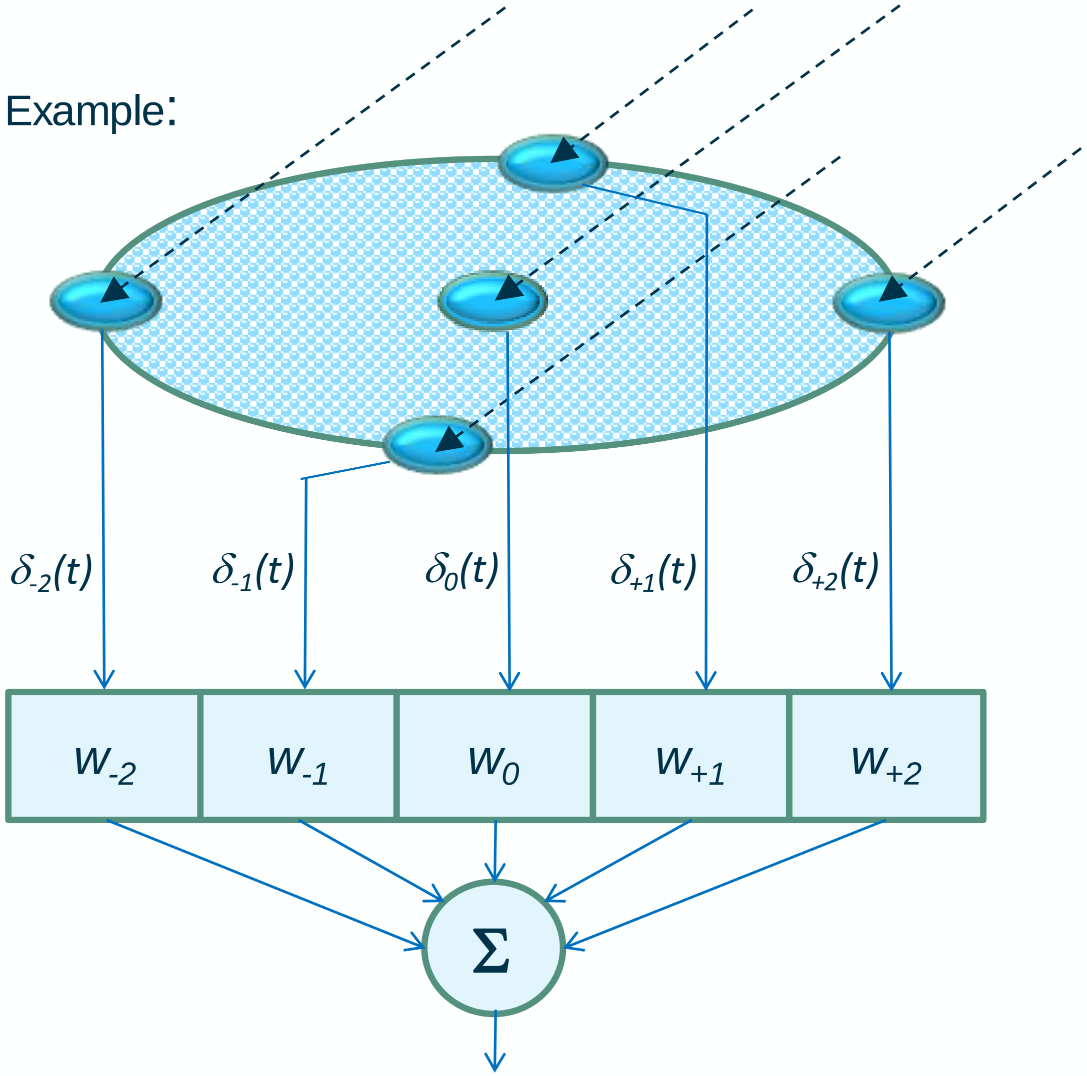
Very large number of monitoring methods for RFI detection. Some examples:

- Analysis of anomalies on the signal stream properties:
  - Frequency domain: by Fourier transform analysis
  - Time domain: by correlators output analysis (e.g. statistics)

- Analysis to its conformance to predefined RFI signals:
  - Chirp signals, by Fractional Fourier transform analysis
  - Pulsed signals by correlation with a pulse-mask analysis.

Localisation Techniques. DOA.

Example:



- Antenna array processing technique.
  - Linear combination (complex coefficients) of instances of the interference signal, each with a different delay (i.e. different antenna element).

- For generic interferer:
  - Coefficients vector choice minimize output power pre-correlation, for given vector norm.
  - Shapes antenna pattern by minimizing gain towards interferer(s) direction.

Localisation Techniques. DOA.

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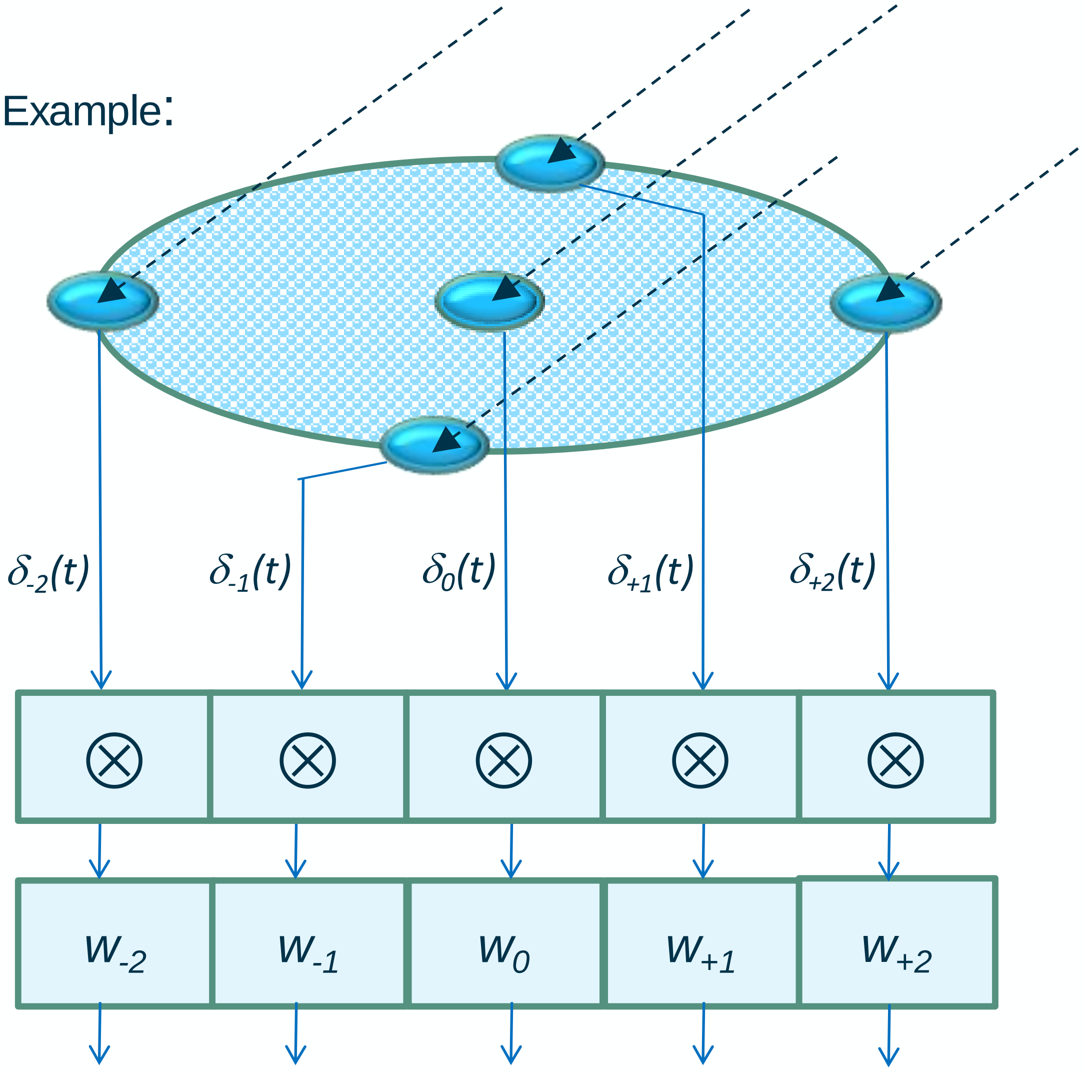


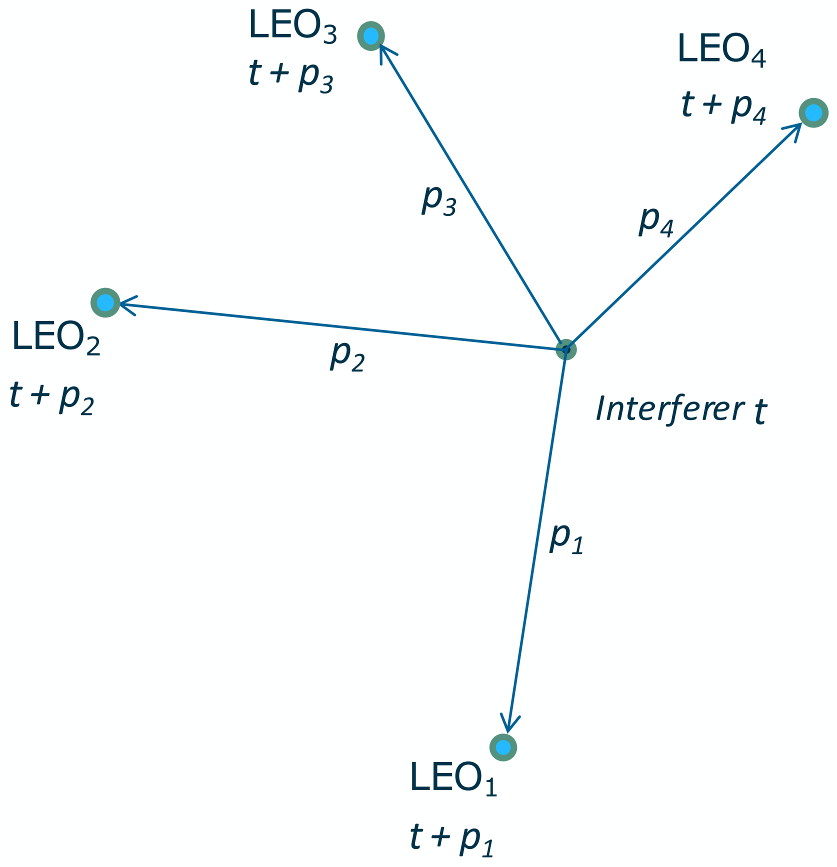
- Antenna array processing technique.
  - Linear combination (complex coefficients) of instances of the interference signal, each with a different delay (i.e. different antenna element).

- For predefined RFI(*):
  - Coefficients vector choice maximize output power post-correlation, for given vector norm.
  - Shapes antenna pattern by maximizing gain towards interferer(s) direction.

(*) prior knowledge on interference signal at RX

Localisation Techniques. TDOA.

- For generic interferer:



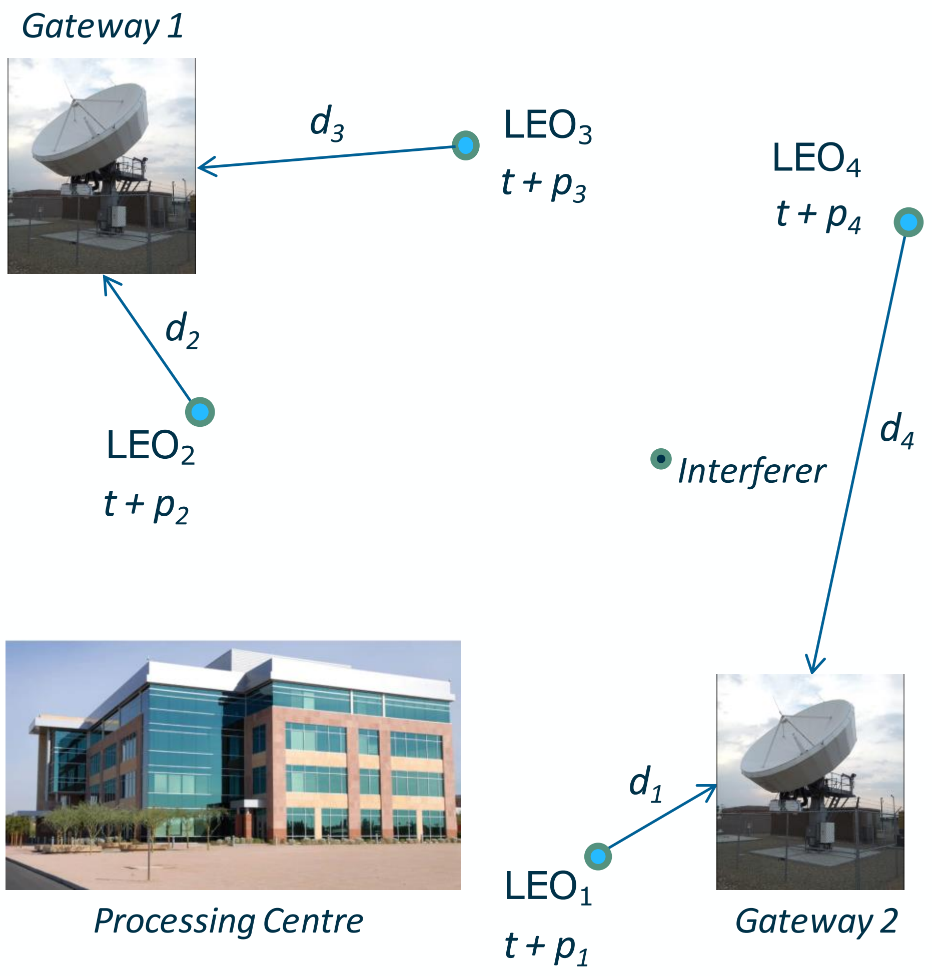
- Conceptual measurement: time, from on-board clock, at which interference condition is detected.

$$t_j = t + p_j(t) + c_j + b_{jc} + b_{jd}$$

  - p_j(t): propagation time from emission at time *t*, upon arrival to LEO*j* antenna.
  - c_j : on board clock error (known from GNSS RX)
  - b_{jc} : common latency of the interference monitor (can be interference-type specific)
  - b_{js} :satellite delays

- Actual measurement: signal-fragment simplified description (e.g. spectrum) over successive chunks.

Localisation Techniques. TDOA.

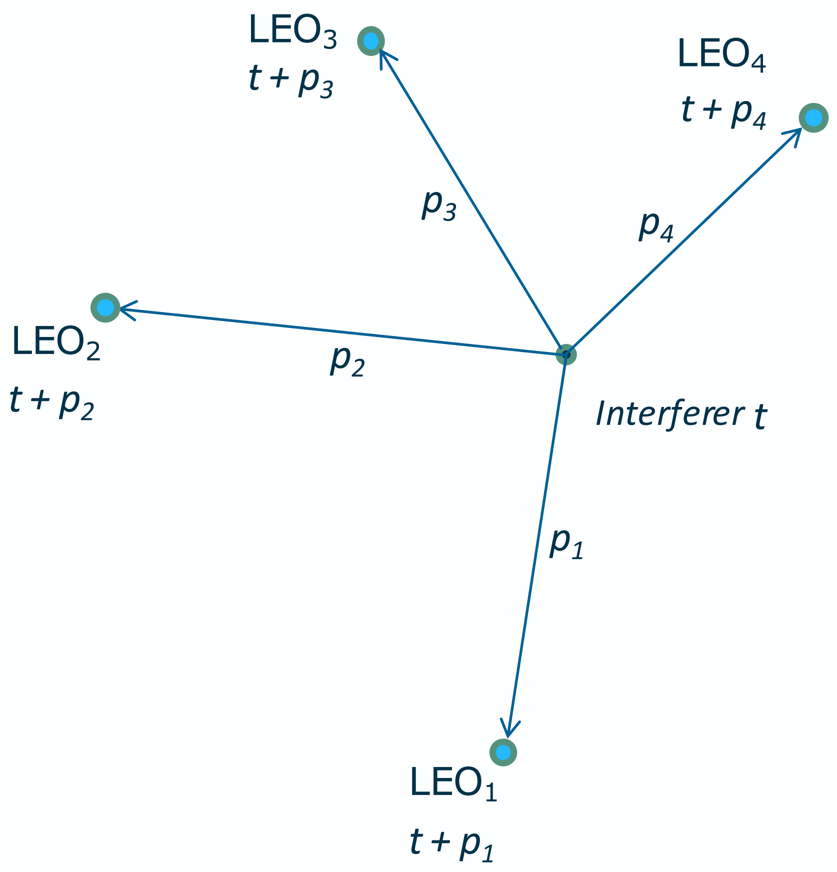


- Signal-fragments simplified description delivered to Processing Centre, via Gateway stations, what may require of a considerable time.
- Processing signal-fragments from different LEO satellites allows identification of common interference events, and their TOAs at each LEO.
- Differential TOA (DTOA) cancels common monitor related errors on TOA (some interference specific)

$$\{\Delta t_{j,k}\}_{j,k} \approx \{p_j(t) - p_k(t)\}_{j,k}$$

Localisation Techniques. TOA.

- For predefined RFI:



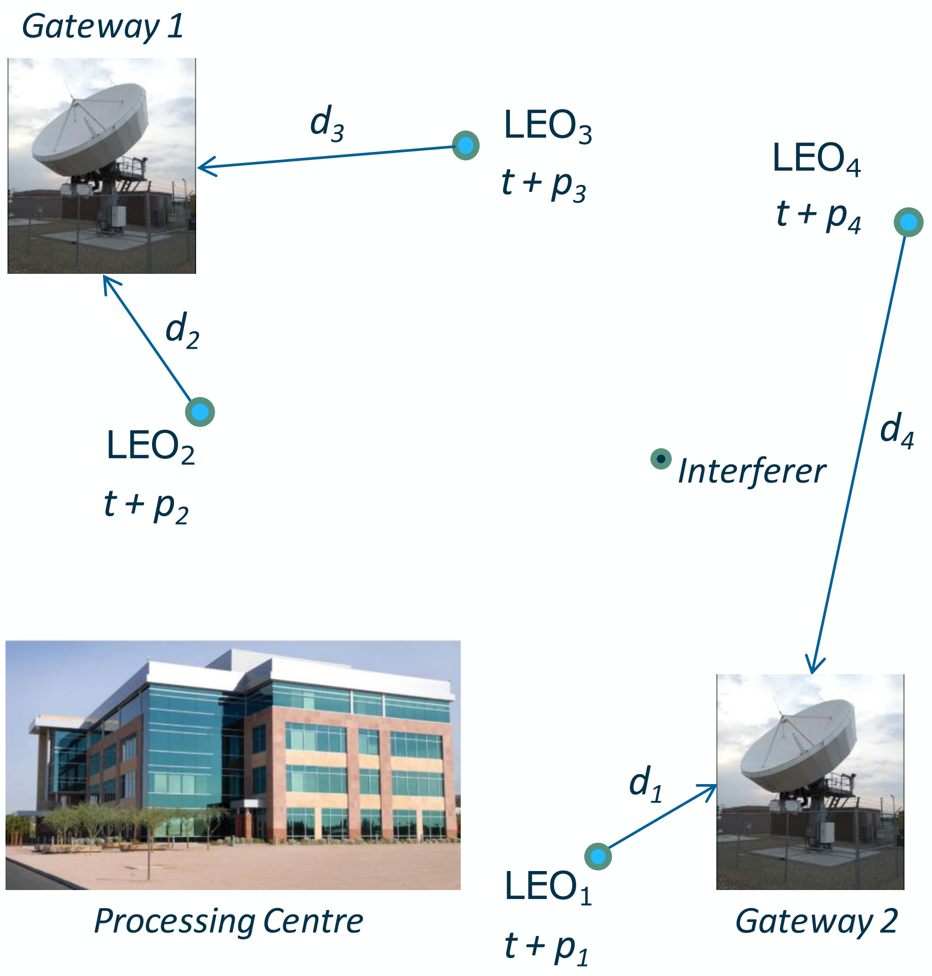
- Conceptual measurement: time, from on-board clock, at which interference condition is detected.

$$t_j = t + p_j(t) + c_j + b_{jd}$$

  - p_j(t): propagation time from emission at time *t*, upon arrival to LEO*j* antenna.
  - c_j : on board clock error (known from GNSS RX)
  - b_{jd} :satellite delays

- Actual measurement: pseudo-range LEO*j* - Interferer.

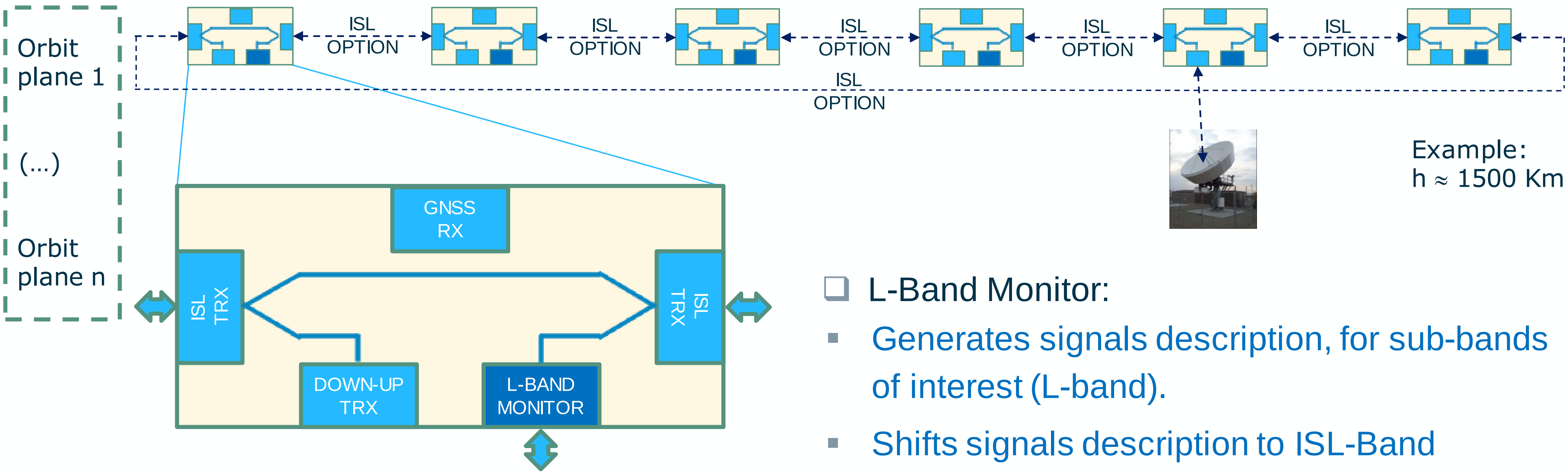
Localisation Techniques. TOA.



- Pseudo-ranges delivered to Processing Centre, via Gateway stations, what may require of a considerable time.
- Processing pseudo-ranges from different LEO satellites allows PVT of jammer, because LEO positions and clocks are known (GNSS RX) .
- Much higher achievable accuracy.

Space System for Monitoring and Localisation

Space System. Constellation.



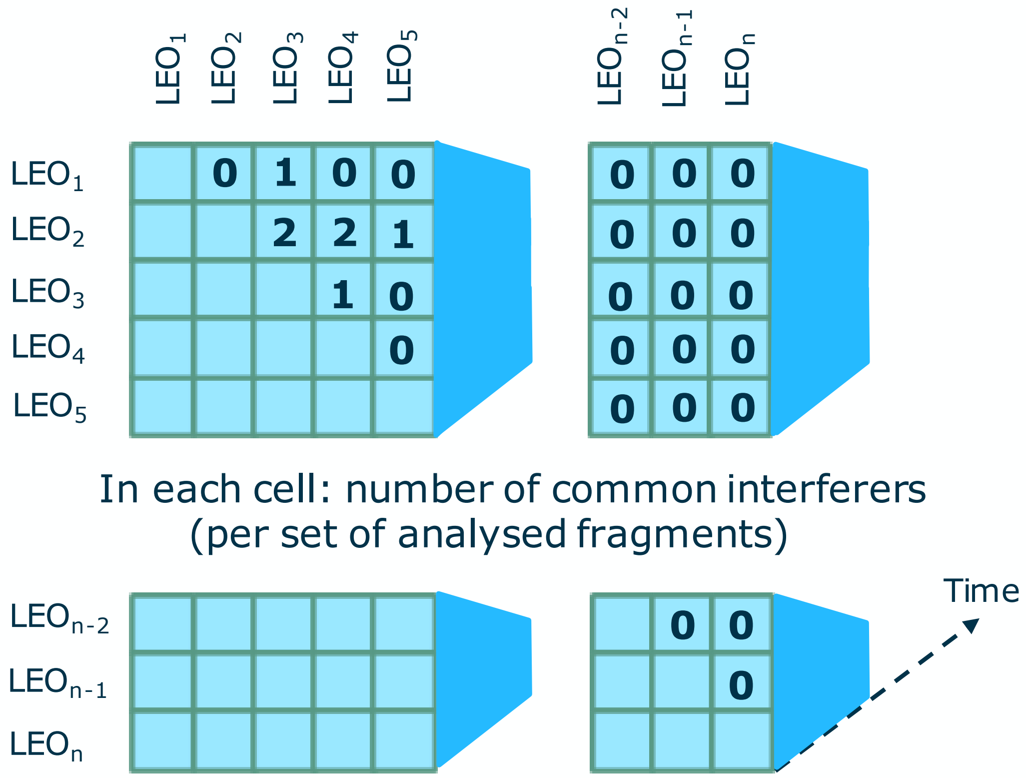
- ❑ L-Band Monitor:
  - Generates signals description, for sub-bands of interest (L-band).
  - Shifts signals description to ISL-Band

- ❑ D/U-communication equipment:
  - Relays signals description to gateway

- ❑ ISL-communication equipment (option):
  - Relays signals description from/to the rear to/from the front satellite, and integrates in this flow the signals description from the monitor.

Space System. Ground infrastructure.

- For generic interferer:



In each cell: number of common interferers
(per set of analysed fragments)

- RFI-LEOM Monitor:
  - Cross-correlation software analysis processing signal description fragments:
  - Multiple RFI signals may exist simultaneously.
  - Coarse localization: from DTOA measurements analysis, screening different hypothesis in terms of space-time coordinates of the interferer.
  - Fine localization: from DTOA measurements linearized observations equations.
  - Redundancy check: based on the analysis of the DTOA measurements residuals in the linearized observation equations.

RFI-LEOM System Targets.

RFI-LEOM Project. Performance Targets.

- **Service Volume**

Volume 1	▪ Latitude: [+20°, +80°] ▪ Longitude : [-40°, +40°] ▪ Height: [Sea-level/Ground-level, 20000 m]	RFI-LEOM System Maximum performance
Volume 2	▪ Latitude: [-090°, +090°] ▪ Longitude : [-180°, +180°] ▪ Height: [Sea-level/Ground-level, 20000 m]	RFI-LEOM System Minimum performance

Note: for ISL option RFI-LEOM system maximum performance globally

RFI-LEOM Project. Performance Targets.

- **Monitored sub-bands within Galileo open service signals - possibility to extend for other GNSS signals**

Sub-band name	Central carrier (*)	Bandwidth (**)
GAL E5a	115 fo	40.920 MHz
GAL E5b	118 fo	40.920 MHz
GAL E1	154 fo	16.368 MHz
GAL E6	125 fo	20.460 MHz
(*) Note: fo = 10.23 MHz (**) Note: including main lobe plus side lobe		

RFI-LEOM Project. Performance Targets.

☐ **RFI-LEOM System capability.**

Monitoring Functions	▪ Spectrum sampling ▪ Power time series ▪ Polarization ▪ Direction of arrival		
Performance	Volume 1	High power interferers	Coarse-detection latency < 05 minutes Coarse-localisation error < 10 Km Fine-detection latency < 60 minutes Fine-localisation error < 01 Km **Note: for ISL option near-real time.**
	Volume 2	High power interferers	Under evaluation.

RFI-LEOM Project. Implementation constrains.

- **RFI-LEOM Implementation constrains.**

Number of LEO satellites hosting RFI-LEOM instrument	< 100
Space borne RFI-LEOM instrument mass	< 30 Kg
Space borne RFI-LEOM instrument antenna envelope	< 50 cm (max diameter)

RFI-LEOM Project. Conclusions.

- RFI-LEOM is a running exploratory study, which designs a spectrum monitoring-system, for Galileo OS signals, based on space-borne monitors at LEO orbit.
- Targets the detection of generic and predefined RFI.
- Provides worldwide coverage, including oceans.
- Provides RFI localization by means of TDOA, TOA and DOA techniques
- Based on architecture in which the satellites are sensors, & the actual detection and localization is based on ground processing.
- Minimum performance targets have been identified.

Thank you for your attention