Characteristics for an Interoperable GNSS Space Service Volume

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Presentation Objective and Overview

- Objective of this presentation is to identify GNSS system specific **characteristics** in order to allow for an interoperable Space Service Volume (SSV)

- Content:
  - GNSS in Space:
    - Applications overview
    - GNSS constraints in space
    - PVT space user's specification
    - Transmit antenna pattern
  - SSV Performance at LEO and GEO. Simulation results
  - GNSS Space Service Volume (SSV):
    - SSV Specification
  - Closing Remarks

GNSS Space Applications

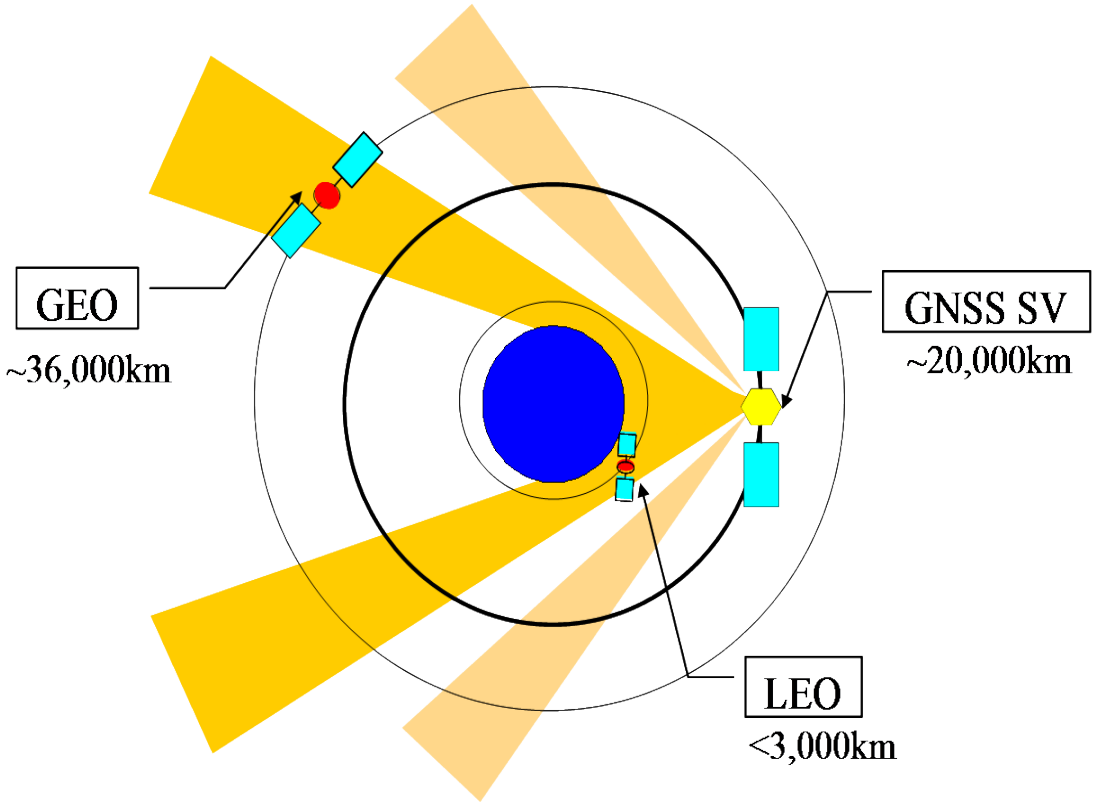
- Main applications of GNSS in space:
  - Orbit determination
  - AOCS & Timing
  - Formation Flying & Rendezvous
  - Scientific instruments (RO, Reflect.)

- GPS is being used at LEO and GEO orbits
- Several studies done at ESA about the benefits of adding the new GNSS system, including Galileo
- Several GNSS technologies under development, new ASICs and receivers

Orbit	Mission examples
LEO	GOCE (295km), ATV (400 km), Sentinels, Swarm, MetOp, EarthCare
MEO	GNSS, GTO
GEO	Telecomm, EO, SGEO
Beyond GEO	HEO, STE-QUEST

GNSS Constraints in Space

- GNSS key constraints in space wrt an Earth's user:
  - Higher Doppler and Doppler rate
  - Fewer signals available (in MEO/GEO)
  - Lower received power, especially at GEO and beyond
  - Larger dynamic ranges, especially at MEO



GNSS Space User Specification

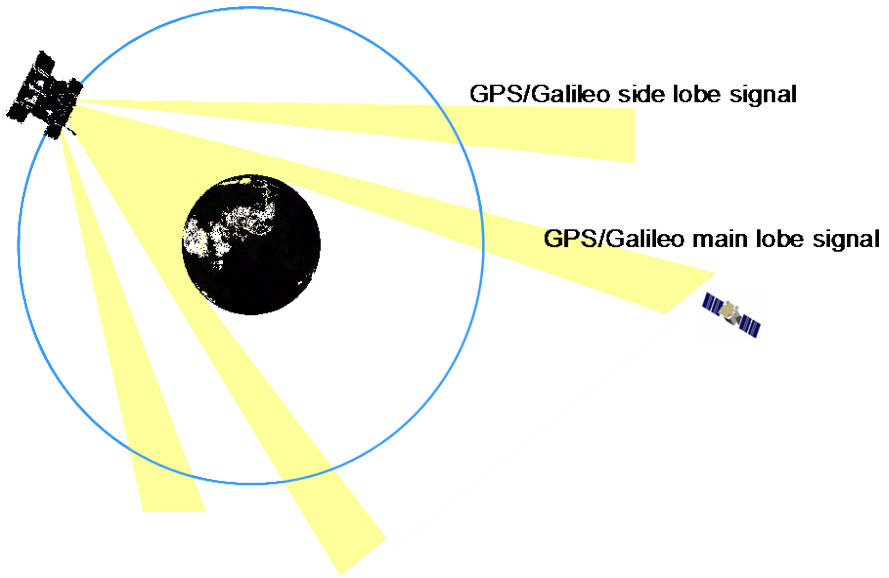
User Specification. PVT accuracy On-board Real-time

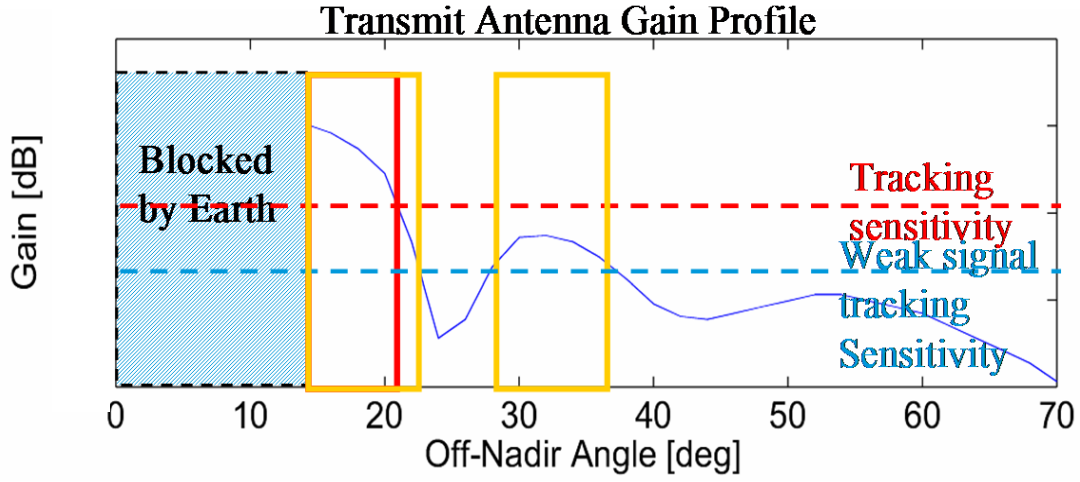
Orbit	Altitude (km)	Orbit Coverage	PosRq (m)	VelRq (m/s)	Time
LEO	200 - 3000	LEO, HEO perigees	1-20	0.1-0.01	1 ms- 1μs
Low MEO	3000- 8000	MEO, GTO, HEO perigees			
High MEO	8000-36000	MEO, GTO			
GEO	36000	GEO, IGSO	50-150	0.1-0.01	1 ms- 1μs
Beyond GEO		HEO apogees			

- 8000 km is TBC. It would need consolidation for all the GNSS systems (probably lower)
- Up to 8000 km is defined to include the tracking of the main lobe from a Rx zenith antenna
- Above 8000 km the tracking is performed over the limb of the Earth from a Rx nadir antenna
- The use of the secondary lobes is very important for MEO/GEO users
- An spacecraft crossing trough the high and low MEO regions (GTO, HEO) will need to carry two antennas, 1 at zenith and 1 at nadir, to have continues tracking of the GNSS signals

Transmit Antenna Pattern

- The transmit antenna is a key element for the SSV specification:
  - Cmin and Nsat strongly depend on the transmit radiation pattern
  - LEO is well covered by the main lobe
  - Higher orbits needs the full main lobe (~20 deg) and the secondary lobes





Not a true radiation pattern

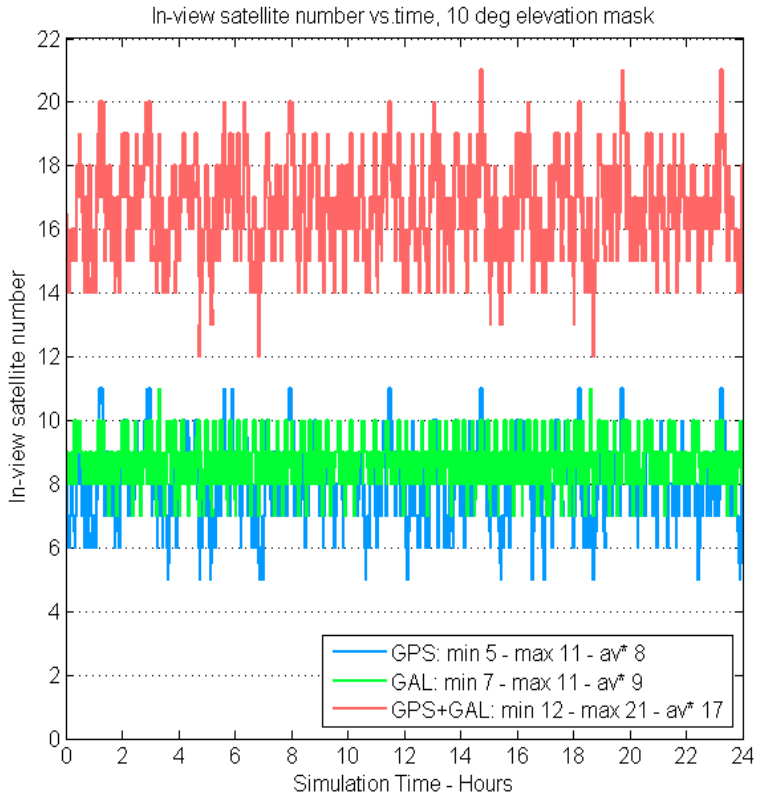
SSV Performance Examples

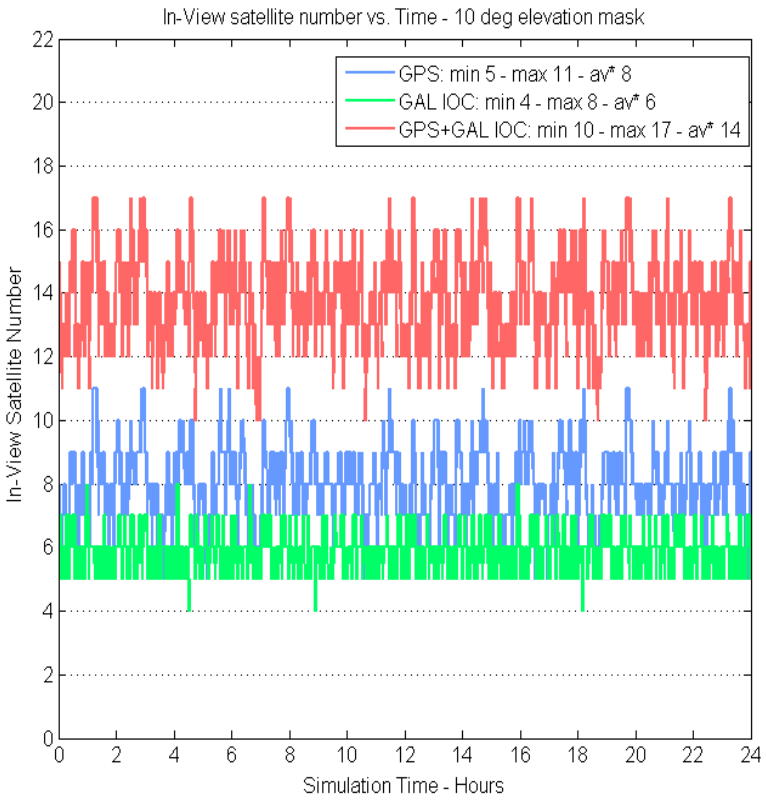
Reference Scenarios

Orbit	Altitude (km)	Mission	Rx Antenna
LEO	817	MetOp	1 zenith
GEO	36000	MS3G	1 nadir

- Several simulations performed on the two scenarios
- Main simulation assumptions:
  - GNSS constellations: GPS + Galileo
  - SISRA: clock and orbit residuals
  - LEO Rx: standard Rx C/No_{th}>27 dBHz. Omni-directional antenna
  - GEO Rx: high sensitivity Rx C/No_{th}>20 dBHz. Medium gain antenna (12 dBi)
  - PVT computed using a kalman filter with a reduced dynamic model

Visibility at LEO





GPS and Galileo (FOC left, IOC right) visibility vs. time at LEO (817 km)

Minimum Received Power at GEO

	Signal	Galileo Sat. antenna beamwidth	
		12.5 deg	Full main lobe
Minimum Received Power (dBW)	E1		
	E5		
	E6		

Minimum power from a 0dBi at GEO

- With 12.5 deg, the % of time with more than 1 or 2 usable satellites is low.
- It is necessary to specify a lower Cmin and a wider reference bandwidth to increase the availability to 100%. These values should be part of a dedicated analysis

PVT Performance at LEO / GEO

PVT simulation results

Orbit	Altitude (km)	Mission	Pos rms (m)	Vel rms (m/s)	Time
LEO GPS	817	MetOp	2	0.01	
LEO GPS + Galileo	817	MetOp	1.5	0.01	100 ns
GEO GPS + Galileo	36000	MS3G	30	0.05	1 us

- The final S/C navigation performance (PVT) will strongly depend on the type of receiver, antenna, signal processing, navigation filter and potential integration with other sensors

GNSS Space Service Volume (SSV) Specification

- GNSS system parameters impacting the navigation performance:
- Minimum received power (Cmin) that declares a GNSS satellite as usable (Cmin/No>Thrsld).
- Minimum number of usable GNSS satellites (Nsat) available 100 % of the time.
- System contribution to the pseudorange accuracy (SISRA: clock, ephemeris)

Orbit	Altitude (km)	Antenna	Cmin	Nsat	SISRA
LEO	200 - 3000	1 zenith			
Low MEO	3000- 8000	1 zenith			
High MEO	8000-36000	1 nadir			
GEO	36000	1 nadir			
Beyond GEO		1 nadir			

Parameters to be identified per service provider and signal.

- These parameters should be part of a harmonisation exercise among the different GNSS systems providers

Closing Remarks

- PVT specification is not adequate for space users at GNSS system level. PVT has to be transformed in SSV system specification: **Cmin, Nsat, SISRA**
- Harmonisation among the different GNSS system providers is required for the SSV specification
- Galileo's current OS ICD does not include spec for space users
- LEO orbits are expected to be well covered by the GNSS systems. Low MEO orbits up to 8000 km (TBC) as well
- For higher orbits, the transmit antenna beam-width has considerable impact in the SVS performance. Galileo OS ICD specifies minimum received power at the Earth's surface.
- At GEO, multiple GNSS constellation is needed to overcome the low number of usable satellites (100% of time) from a single GNSS system