COMET ORB –
GNSS SATELLITES ORBIT DETERMINATION IMPROVEMENTS AND APPLICATIONS

INTRODUCTION TO GNSS POSITIONING METHODS

MARIE ANSART – MARIE.ANSART@THALESALENIASPACE.COM

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TABLE OF CONTENT

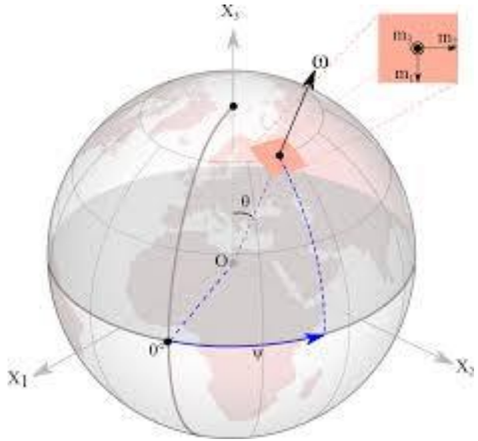
BASIS OF GNSS POSITIONING

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

REFERENCE FRAME AND TIME SCALE

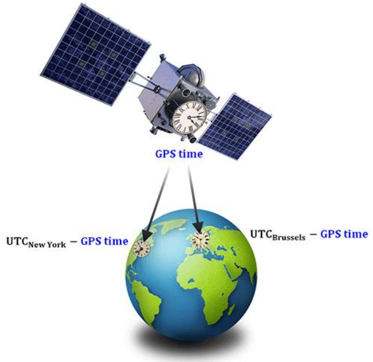
/// Reference frame

- Position and velocity should be given relatively to a reference frame or coordinate system
  - GPS: WGS84
  - GALILEO: GTRF



/// Reference time scale

- Time should be given with respect to a reference time scale (steered to UTC)
  - GPS: GPST
  - GALILEO: GST



Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

COMPUTATION OF 3D POSITION

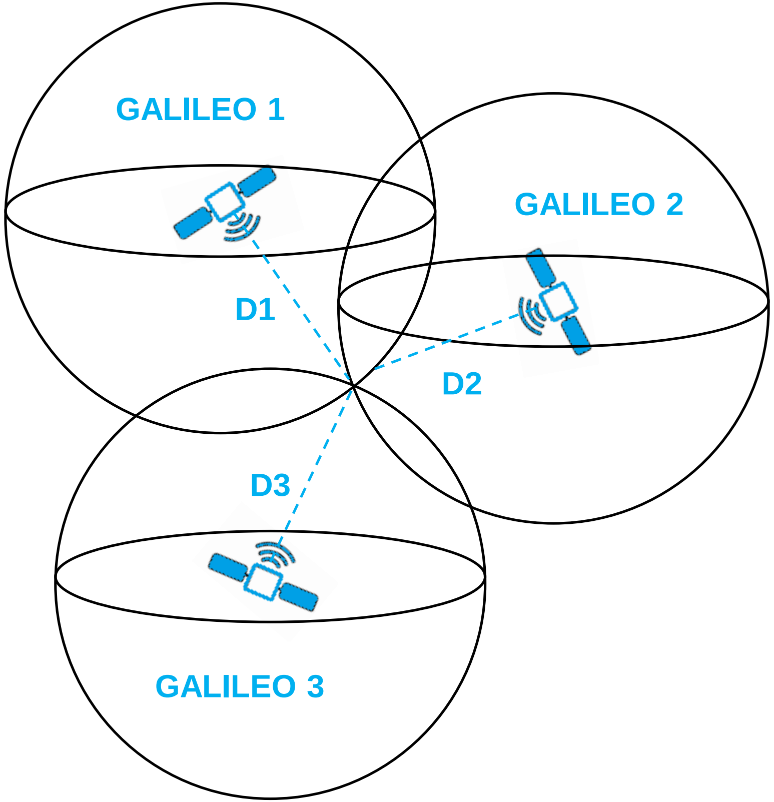
/// 3 equations, 3 unknowns

- x_u, y_u, z_u (‘u’ for user)

$$\sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} = D1$$

$$\sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} = D2$$

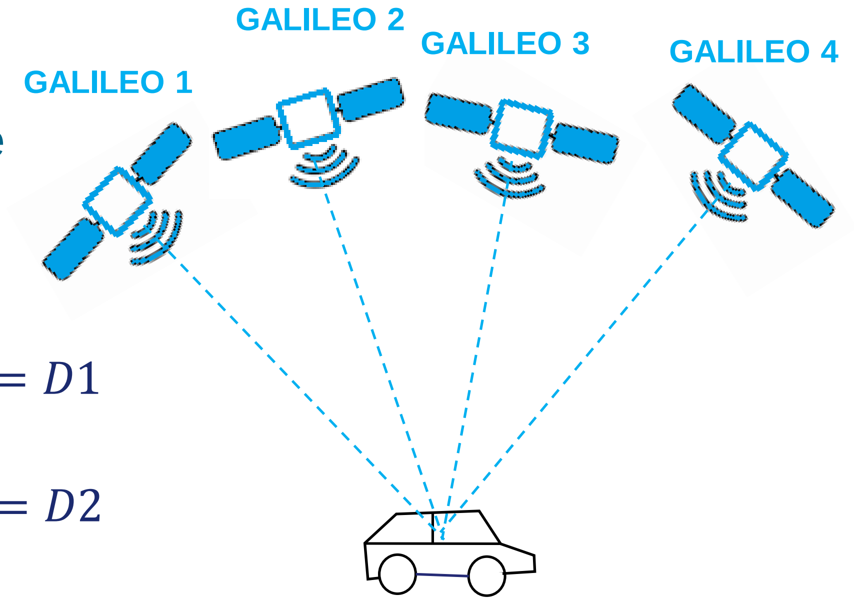
$$\sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} = D3$$



Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

MINIMUM OF 4 SATELLITES FOR GNSS APPLICATIONS

/// The satellite clock offset with respect to reference time scale is given in the navigation message while the distance due to user clock bias should be added as a fourth unknown (b_u)



$$\sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + b_u = D1$$

$$\sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + b_u = D2$$

$$\sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + b_u = D3$$

$$\sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + b_u = D4$$

PERTURBATIONS THAT INDUCE SIGNAL DELAYS

/// The signal is impacted by various sources:

- Ionosphere
- Troposphere
- Interference
  - Involuntary
  - Jamming
  - Spoofing
- Multipath
- Receiver Noise
- Hardware bias
- Clock relativistic effect
- …

ABSOLUTE AND RELATIVE TECHNIQUES

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

ABSOLUTE AND RELATIVE TECHNIQUES

/// Absolute techniques include: SPP, SBAS, PPP, PPP-RTK

- SPP: Standard Point Positioning (stand alone method)
- SBAS: Satellite Based Augmentation System (used for aviation)
- PPP and PPP-RTK: precise positioning methods (down to centimer-level performance)

/// Relative techniques include: DGNSS (DGPS, DBAS, RTK)

- DGPS: every country deploys radio-beacons along the coasts to help Maritime Navigation up to a range of 100km. These reference stations transmit the differential corrections to the boats.
- DBAS: equivalent of DGPS but for aviation and with reference stations in a specific area
- RTK: dense grid of stations to provide differential corrections that include all contributors

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

PRECISE POSITIONING

CHOICE OF APPROACH FOR METER-LEVEL PERFORMANCE

/// 2 options

- **OSR** (**O**bservation **S**tate **R**epresentation) approach: correction at pseudo range level

- **SSR** (**S**tate **S**pace **R**epresentation) approach: distinction between corrections for orbit, clock and ionosphere)

- Satellite Ephemeris Correction Parameters;
- Satellite Time Correction Parameters;
- Code Phase Measurement Correction Parameters;
- Ionospheric Delay Correction Parameters

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

EXAMPLE OF QZSS SLAS (SUB-METER LEVEL AUGMENTATION SERVICE)

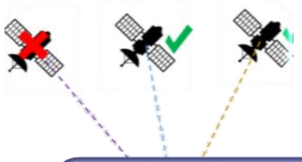
///Use of OSR (Observation State Representation) method

DGNSS (Differential GNSS)

- Principle: the error for a user and for a known fixed monitoring station is similar if the user is close enough to the station.
- Correction at pseudo range level (errors not segregated by source)

Selection of the MS

- Apply to the user the correction used for the nearest station
- Use of the second nearest station in case the closest one is unhealthy



Selection of the augmentated satellites

- Healthy satellites with elev > 5deg

$$PR_i^{corrected} = PR_i^{measured} + PRC_i$$

$PR_i^{corrected}$: Corrected Pseudorange
$PR_i^{measured}$: Measured Pseudorange
PRC_i : Pseudorange correction
i : PRN number

Calculation of correction

- Error on pseudorange
- Weights of contributions (pseudorange error, receiver noise, multipath, ionosphere)

Alert information

- Exclusion of unhealthy satellites in case of alert

User algorithm

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

OVERVIEW OF SSR METHOD

///Use of SSR (State Space Representation) method

- In SSR approach, corrections are sent per contributor: satellite orbit and clock and ionosphere

- The SBAS receiver applies the GNSS navigation message plus the broadcast SBAS corrections on the top of it:

  - Satellite Orbit Corrections

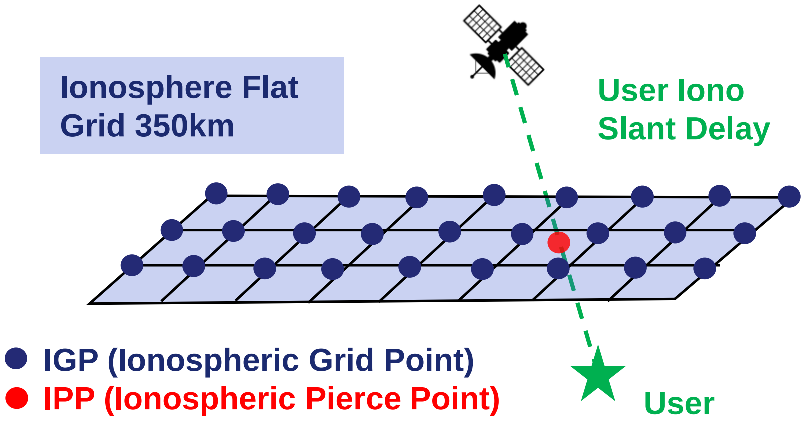
$$r_{SBAS}^{i} = r_{NAV}^{i} + LTC_{ORB}$$

(LTC = Long-Term Corrections ; FC = Fast Corrections)

  - Satellite Clocks Corrections

$$b_{SBAS}^{i} = b_{NAV}^{i} + FC_{CLK} + LTC_{CLK}$$

- The SBAS needs to provide an independent and better Ionosphere Model than the classical navigation message



CHOICE OF APPROACH FOR CENTIMETER-LEVEL PERFORMANCE

- **PPP** (global approach): Kalman filter to estimate all the parameters including the phase ambiguities
- **RTK** (local approach): regional application →user close to known monitoring station network. Interpolation among known corrections from close reference locations.
- **PPP-RTK (=SSR-RTK)** (mix between global and local approaches): transmission of PPP corrections with parallel broadcast of precise corrections on troposphere and ionosphere thanks to a dense GNSS station network. It is called the SSR concept.
  - Satellite Ephemeris Correction Parameters;
  - Satellite Time Correction Parameters;
  - Code Phase Measurement Correction Parameters;
  - Carrier Phase Measurement Correction Parameters;
  - Ionospheric Delay Correction Parameters;
  - Tropospheric Delay Correction Parameters;
  - Ranging Accuracy Information.

Table 0.2: Corrections required to support PPP, PPP-AR and SSR (or PPP)-RTK.

	PPP	PPP-AR	SSR-RTK
Satellite orbits	✓	✓	✓
Satellite clocks	✓	✓	✓
Code biases	×	✓	✓
Phase biases	×	✓	✓
Ionospheric delay	×	×	✓
Tropospheric delay	×	×	✓

Source: Thales Alenia Space & RMIT University Collaboration 1 Report of Tasks 1 and 2 (PPP-AR=PPP-Ambiguity Resolution)

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

EXAMPLE OF QZSS CLAS (CENTIMETER LEVEL AUGMENTATION SERVICE)

/// Based on RTCM format – SSR concept

Classical PPP for dual receivers
- Correction of orbits, clocks and biases

→

Precise correction of ionosphere (with STEC) and troposphere

/// Use of PPP-RTK

- Principle:
  - Classical PPP with delta corrections with respect to navigation message parameters (orbit, clock, biases)
  - RTK layer: additional regional corrections of ionosphere and troposphere (grid model per sub-region) → user interpolation required

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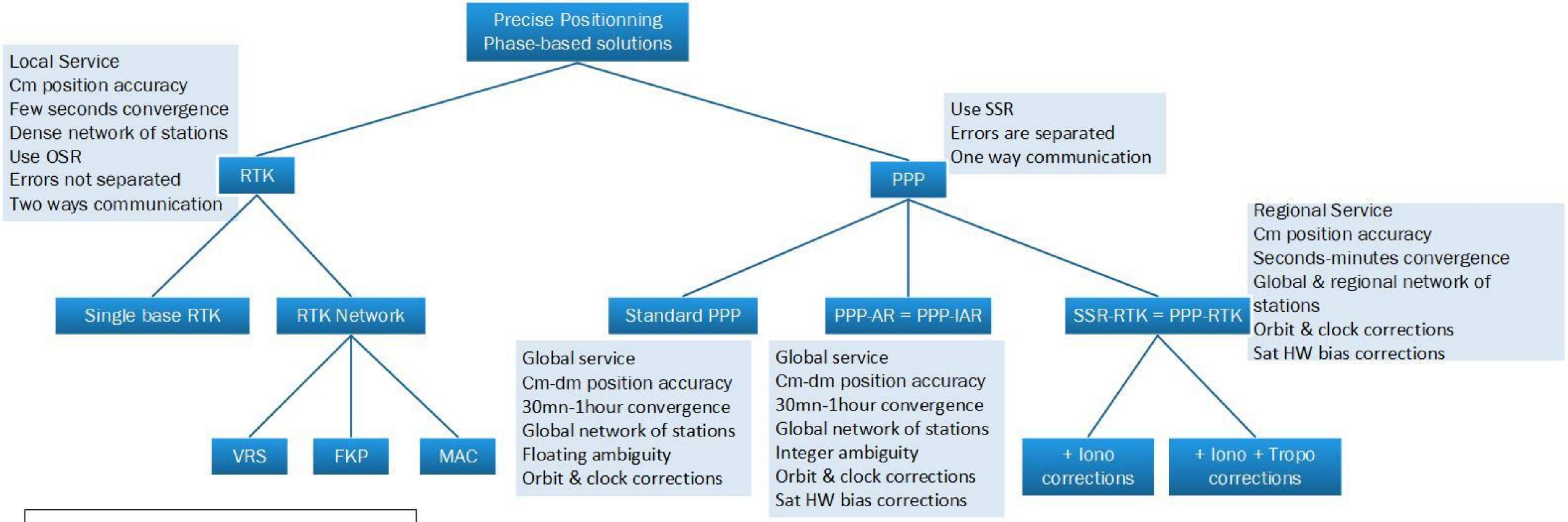
Ref:
Template: 83230347-DOC-TAS-EN-011

SUMMARY OF PRECISE POSITIONING METHODS

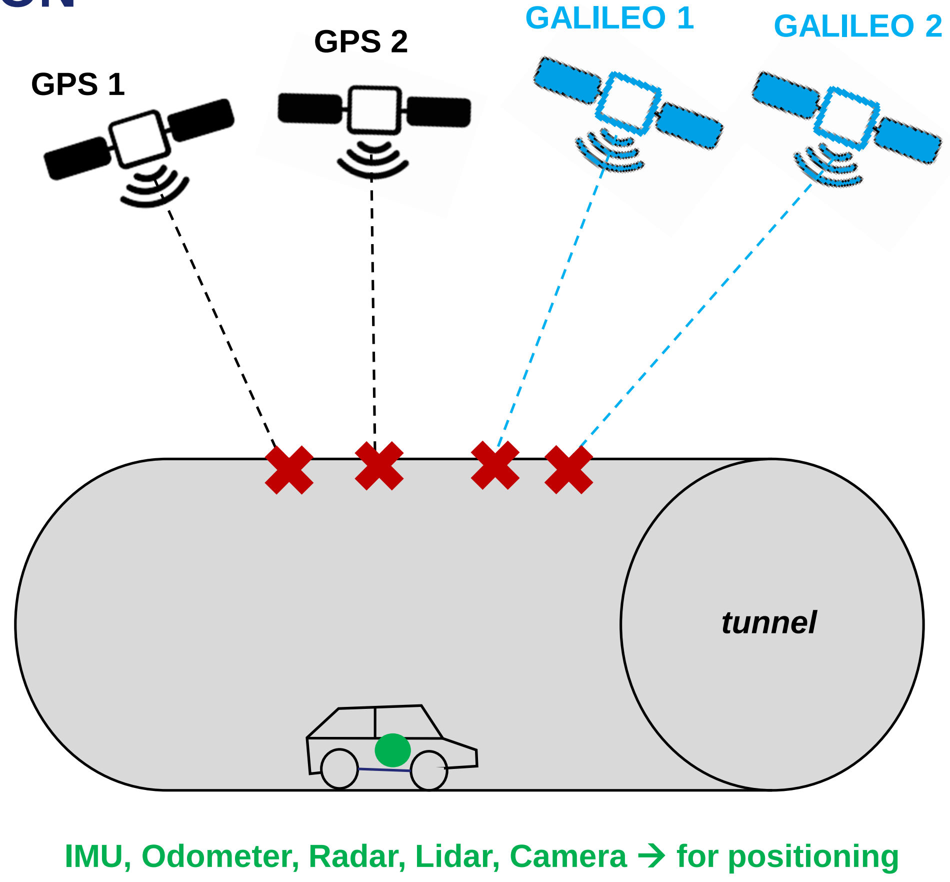


OSR = Observation State Representation
SSR = Space State Representation
VRS = Virtual Reference Station
FKP = Flat Correction Parameter (in german)
MAC = Master Auxiliary Concept
RTK = Real-Time Kinematic
PPP = Precise Point Positionning
IAR = Integer Ambiguity Resolution

Date: 21/01/2025
Ref:
Template: 83230347-DOC-TAS-EN-011

HYBRIDIZATION – SENSOR FUSION

- If the GNSS signal is not available, in-situ sensors should take over
  - Typically in harsh environment (city with very high buildings, tunnels, …)
- Example of sensors: IMU, Odometer, Radar, Lidar, Camera,…

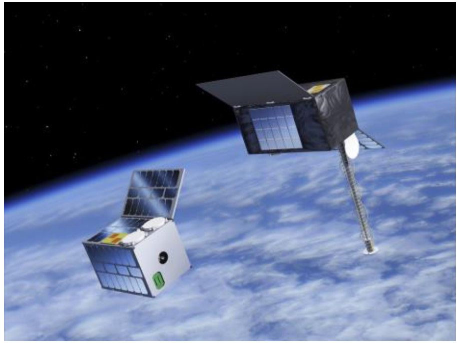


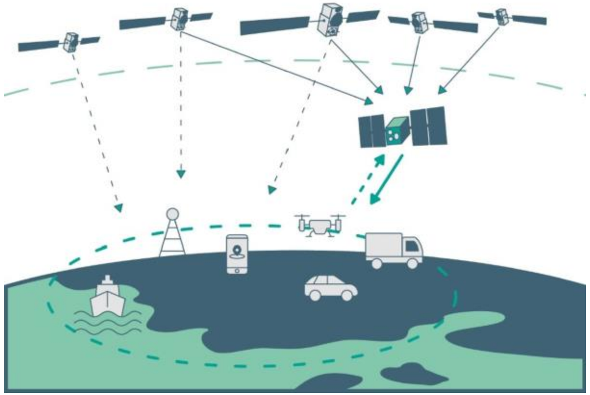
GNSS LEO CONSTELLATION

/// **New dissemination capabilities** -> LEO satellites serve as a complementary network to enhance (in speed or volume) the dissemination of classical services associated with the use of MEO GNSS.

/// **System Performance improvements** -> LEO satellites perform on-board GNSS measurements and act as “flying stations”. The gain in additional observables improve the quality of the orbit determination process for the classical MEO GNSS services

/// **New signals for users** -> LEO satellites are capable of broadcasting a positioning service associated with their own orbits, clocks, corrections, etc., just like the current MEO GNSS.





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