Assessing the potential of VLBI transmitters on next generation GNSS satellites for geodetic products

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Outline

Motivation

- Global effort to improve the space geodetic techniques contributing to the Global terrestrial reference frames
- Global Geodetic Observing System (GGOS) scientific requirements have not been fulfilled yet
- Investigation of new observation types to the GNSS satellites and its impact on the geodetic parameters (German Research Foundation funded project NextGNSS4GGOS)
- The new observation type includes transmitters on NextGNSS satellites for Very Long Baseline Interferometry observations (VLBI) and retro-reflectors for Satellite Laser Ranging (SLR) and optical inter-satellite links
- In this study, we focus on the observations of the VLBI transmitter on one Galileo-like MEO satellite

Setup

Simulation strategy

- **Software:** EPOS-OC (Zhu et al., 2004)
- **Station network:** 16 stations
- **Sources:** 64 sources
- **GNSS satellite:** 1 MEO satellite (with VLBI transmitter)
- **Epoch:** 10 days

Recovery of observations

- POD with VLBI to satellite (Mammadaliyev et al., 2022)
- Generation of daily normal equation systems (NEQs) for two scenarios (more on the following slides)

Solution

- Estimated parameters, e.g., orbital parameters (Kepler elements and reduced ECOM parameters), station positions, Earth Rotation Parameters (ERP)
- Stacking of daily NEQs

Scheduling

Assumptions for scheduling VLBI observations

Parameters	
Observation bands	S/X
Min. elevation for satellite observation (deg)	3
Min. elevation for quasar observation (deg)	3
Min. quasar obs. at start and end of session (mins)	60
Ratio between quasar and satellite observation	6.5
Noise added to all participating stations	30 ps ($\sim$10 mm)

Simulation scenarios

Scenario 1

VLBI: Quasars only

- NNT and NNR conditions applied (1 mm)

Scenario 3

GNSS-only

- 24 MEO satellites and 124 globally distributed GNSS stations
- NNR condition applied (1 mm)

Scenario 2

- VLBI to quasars + 1 MEO satellite
- Kepler elements and reduced ECOM parameters estimated

Scenario 2a

- NNT and NNR conditions applied (1 mm)

Scenario 2b

- NNR condition applied (1 mm)

Station and source selection

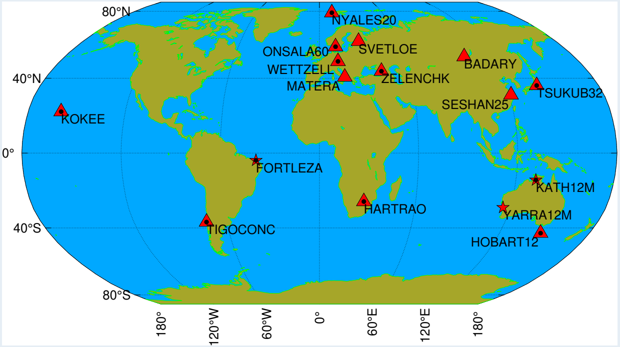
Station network selection

- R1 IVS network, i.e., 13 stations
- Addition of 3 stations located in the Southern Hemisphere to improve geometry

Quasar source selection

- 64 sources

Station network



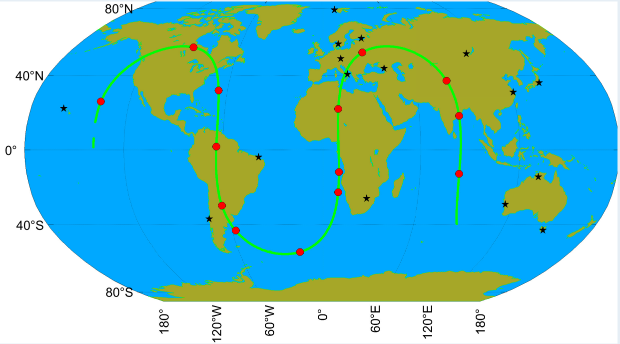
▲ – *R1*; ★ – *Additional*; ● – *Datumstation*

Satellite

Observed ground track of the satellite

- The specifications of the selected MEO satellite are like Galileo i.e., the semi-major axis is 29600 km
- The following figure shows the ground path of the satellite for one day

Ground track

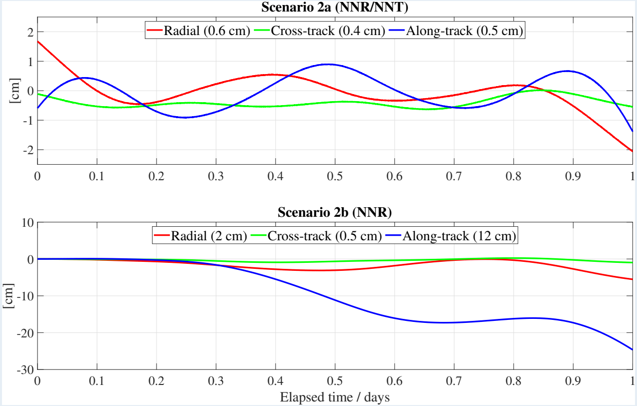


Orbit recovery

Satellite position difference

- We recovered the orbit
- **Scenario 2a:** Recovered on the mm level (NNT/NNR)
- **Scenario 2b:** For along-track, it is up to the dm level, and for cross-track, radial components, on mm and cm levels, respectively (NNR)

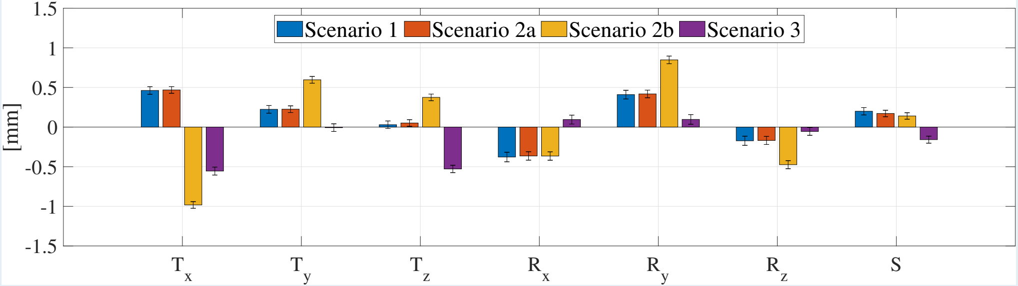
Time-series of the differences for one day (RMS value)



Helmert parameters

7-parameter Helmert transformation parameters (Stacked solutions of 10 days)

- Computed between estimated station positions of scenarios 1, 2a, 2b, and 3 w.r.t. their a-priori and corresponding standard deviations

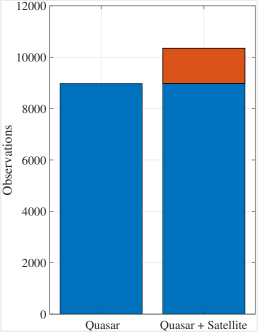


Formal errors of parameters

Expected improvement

- We computed the expected improvement due to different Degrees of Freedom (DOF) for the added satellite observations
- The expected improvement in formal errors is around 6%

No. of Observations

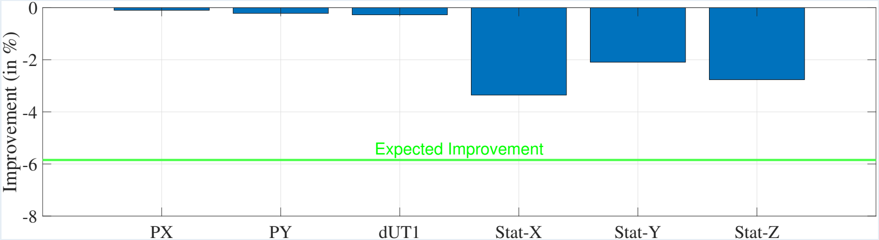


- Blue and red represents quasar and satellite observations for one day

Station positions and Earth rotation parameters

Assessment of parameters w.r.t. expected improvements (formal errors)

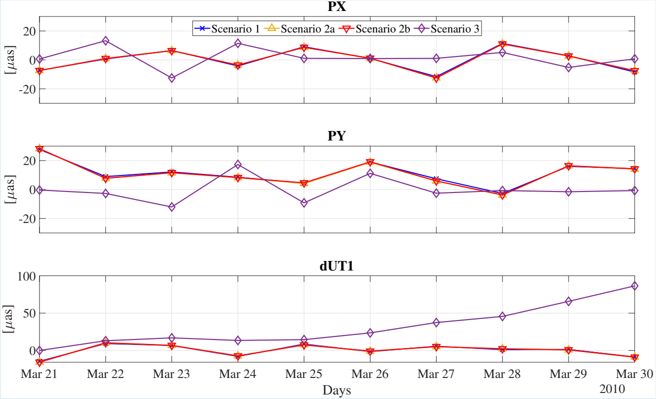
- Computed for scenario 2a (VLBI: Quasar+MEO NNR+NNT) w.r.t. 1 (VLBI: Quasar NNR+NNT)
- The addition of new observations improves the estimated parameters, however not statistically significant



Earth rotation parameters (time series)

Comparison of ERP corrections (10 days)

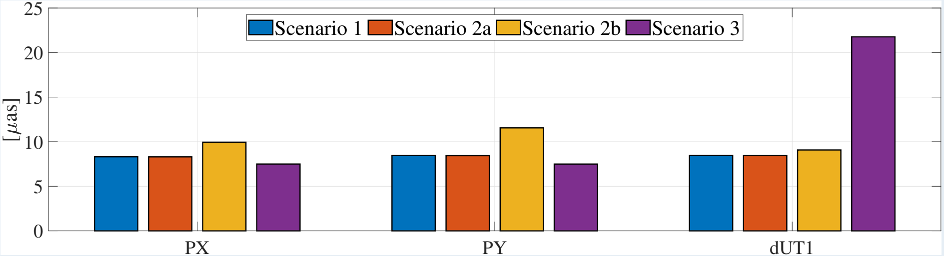
- Scenario 1, 2a, and 2b can determine dUT1 in an absolute sense
- In scenario 3, dUT1 from VLBI is fixed for the first day, and it can only determine LOD



Earth rotation parameters (formal errors)

Comparison of formal errors in ERP (10 days)

- PX and PY from scenarios 1, 2a, and 2b are slightly worse than scenario 3 (GNSS)
- As scenario 3 determines dUT1 from estimated LOD, we observe high formal errors



Conclusions

Summary

- We performed simulations to VLBI transmitter on a MEO satellite with POD in addition to quasars for a period of 10 days
- Orbit recovery
  - **Scenario 2a (NNT/NNR):** mm level
  - **Scenario 2b (NNR):** Along-track, up to the decimeter level, and for cross-track, radial components, it's up to a few cm
  - This is despite having fewer satellite observations
- Helmert Parameters: No NNT condition necessary for VLBI with satellite. Datum can be realized with mm-level
- Addition of the observations to one MEO satellite improves the parameters

Outlook

Future work

- Combination of 'VLBI: quasar+satellite' case with GNSS via space-tie (Mammadaliyev et al., 2021)
- Introducing new observation types such as 'Inter-satellite links' (Giorgi et al., 2019; Glaser et al., 2020; Michalak et al., 2021)

Thank you for listening!

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