Exploitation of Navigation Inter-Satellite Links ranging measurements to enhance Computerized Ionosphere Tomography (CIT) accuracy

Background

As is well known, an electromagnetic wave passing through the atmosphere experience changes in velocity (speed and direction) due to the refraction. In the case of ionosphere layer, the refraction is caused by interaction between the signal and the charged plasma and the entity of this interaction depends on the ionospheric electron density (IED) and the length of the ray path [1]. For GNSS applications, this effect leads to the introduction of a delay in the GNSS signal propagation and an error in the PVT solution gathered by ground-based receivers, if the IED profile is not accurately known. Nowadays, market receivers that exploit free (open) GNSS services rely on ionosphere models (such as Nequick) to evaluate the slant and vertical total electron content (STEC and VTEC) affecting the collected measurements, but the trend of space agencies and industries is to move toward solutions that would grant cm-level accurate Precise Point Positioning, thanks to High Accuracy Services.

One of the most promising technique that is being under study in the recent years to probe the 3D electron content of ionosphere is the Computerized Ionosphere Tomography (CIT) based on multi-constellation GNSS measurements collected by ground-based georeferenced receivers. The fundamental principle of CIT is quite simple. Assuming that the ionosphere can be divided into a discrete number of three-dimensional voxels, each with uniform IED, the ionospheric STEC affecting each satellite-receiver rays linearly depends on the summed value of the IEDs characterizing the voxel crossed along the ray path [2], as in the following equation

$$STEC_i = \sum_j W_{ij} \cdot IED_j + \varepsilon_i$$

in which W_{ij} is linked to the percentage of i-th path crossing the j-th voxel and ε_i is the error. Unfortunately, if only GNSS–ground receiver links are utilized, the geometry constraints limit the inclusion of any horizontal information, making the linear system ill-conditioned.

Many solutions have been proposed to decrease the condition numbers (such as data fusion with ionosondes and data assimilation techniques [3]) with promising results.

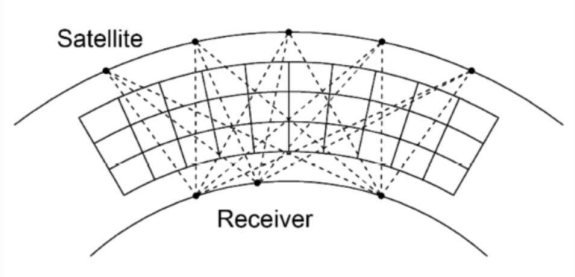
Nevertheless, with the advent of G2G (Galileo 2nd Generation) constellation which is going to incorporate Inter-Satellite Links (ISL) as satellite payload, there will be occasion to take into account measurements crossing the ionosphere in tangential planes wrt the ground surface, providing a considerable improvement to system geometry.

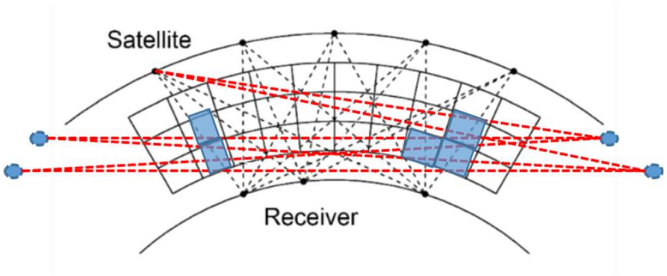
Objectives

In order to demonstrate this improvement and/or to find the most suitable data analysis technique to be employed for including Inter-Satellite Ranging (ISR) measurements into estimation of accurate 3D IED profile estimation, a preliminary study is proposed to be performed with the objective of producing the following outcomes:

- Critical Review of the state-of-the-art techniques to perform CIT using GNSS measurements and resume of technologies involved in ISL on future G2G payload
- A proof-of-concept algorithm, able to simulate the ionospheric environment (through voxels discretization) and the ISL and satellite-to-ground links that would be employed to solve the linear system

- A proof-of-concept algorithm able to provide the optimal choice for a network of dedicated ground GNSS receivers, in terms of number of elements and distribution, that would allow to estimate the IED profile within a given accuracy threshold





Preferred Academic Background

- Electronic or Telecommunication Engineering
- Physics (specialized in astrophysics or weather physics)

Expected competencies

- Good knowledge of at least one programming language (Matlab or Python)
- Good theoretical knowledge of ionosphere environment
- Knowledge of GNSS principle (preferred)
- Knowledge of orbital dynamic (preferred)

References

[1] J. Sanz Subirana, J.M. Juan Zornoza and M. Hernández-Pajares, ESA GNSS Data Processing Book - TM-23.

[2] Lu, Weijun, Guanyi Ma, and Qingtao Wan. 2021. "A Review of Voxel-Based Computerized Ionospheric Tomography with GNSS Ground Receivers" Remote Sensing 13, no. 17: 3432. https://doi.org/10.3390/rs13173432.

[3] Ssessanga, N., Yamamoto, M., Saito, S., Saito, A., and Nishioka, M., “Complementing regional ground GNSS-STEC computerized ionospheric tomography (CIT) with ionosonde data assimilation”, GPS Solutions, vol. 25, no. 3, 2021. doi:10.1007/s10291-021-01133-y.