Galileo SISRE analysis with Where

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At the end of 2016 the European Commission has declared the Galileo Initial Services. The declaration means that the Galileo satellites and ground infrastructure are operational and ready for positioning, navigation and timing to users on the way to full operational capability in 2020.

Galileo performance monitoring plays an important role for testing and verifying the initial services and to ensure the provision of high quality satellite data to users. One of the key performance indicators is the signal-in-space range error (SISRE). SISRE represents the error budget related to the control and space segment of Global Navigation Satellite Systems and can be determined by comparing broadcast against precise ephemerides.

The SISRE analysis is implemented in the geodetic analysis software Where. We will describe the used methodology and we will present the first results of the Galileo orbit performance monitoring based on the SISRE analyses with Where.

Introduction

Signal-in-space range error (SISRE) describes the statistical uncertainty of the modeled pseudorange due to errors in the broadcast orbit and clock information. SISRE is related to errors on the space and control segments. That means influencing factors like clock stability, satellite antenna variation, signal imperfection and predictability of orbital motion for the space segment, as well as orbit and clock determination performance, distribution of monitoring stations, and upload capacity of the control segment [1, 2].

The Norwegian Mapping Authority has established a tool for monitoring Galileo and GPS orbit performance with the implementation of SISRE analysis in the geodetic software package Where. Where determines the global averaged SISRE based on comparisons between broadcast and precise orbit and clock products. The precise products are assumed to represent the truth.

Methodology

The SISRE analysis in Where is mainly based on Montenbruck et al. [3] and will be extended in this section.

Broadcast orbit and clocks refer to the satellite antenna phase center (APC). The precise orbits are related to the center-of-mass (CoM) and the precise clocks to the APC. The APC is chosen as reference point in the SISRE analysis. That means the broadcast and precise orbits and clocks related to APC have to be transformed to the CoM by applying antenna phase center offsets (PCO). PCOs are given by the European Geodetic Service Centre (GSC) and the International GNSS Service (IGS). The average of the GSC PCOs for E1/E5b/E6 frequencies is used [6].

Broadcast and precise clock products are referred to a specific conventional sign of broadcast signal constellation, therefore a group delay correction has to be applied [6]. Where uses the IGS Multi-GNSS Experiment (MGE) differential code bias product of the Chinese Academy of Sciences (CAS) for correcting precise PCOs in the SISRE analysis of I/NAV navigation messages.

For the SISRE analysis it is common to attribute the average contribution over all points of the earth within the visibility cone of the satellite [5], which is called global averaged SISRE. The SISRE analysis in Where is based on the global averaged SISRE:

$$ SISRE(t) = \left( \Delta w_s(t) - \Delta w_s(t-1) \right)^2 + \left( \Delta \omega_s(t) - \Delta \omega_s(t-1) \right)^2 $$

with

- $SISRE$ global averaged SISRE for satellite $s$.
- observation epoch.
- $\Delta w_s$, $\Delta \omega_s$, $\Delta \omega_s$ satellite coordinate differences between broadcast and precise ephemeris in local orbital reference frame with along-track, cross-track and radial coordinates, related to the CoM of satellite $s$.
- $\Delta \omega_s$ satellite clock correction difference related to CoM of satellite $s$ and corrected for satellite biases and averaged over all epochs.
- $\omega_s$: SISRE weight factor for radial errors, $\omega_s = 0.984$ is used.
- $\omega_s$: SISRE weight factor for along-track and cross-track errors, $\omega_s = 0.124$ is used for an elevation mask of 5°.

The SISRE analysis is carried out on daily basis. Each daily solution is cleared for outliers. The outliers are detected and rejected iteratively for each day using a 4-sigma threshold determined for the complete Galileo satellite constellation. After each iteration the SISRE results are again recomputed.

Input data and data preparation

Table 1 gives an overview about the used input files and metadata in the SISRE analysis.

A sampling rate of 5 minutes is used in the SISRE analysis. The transmission time of navigation record is used for selection of the SISRE analysis record based on a given observation time. It should be noted that Where sorts the navigation messages satellite-wise after time of transmission. Afterwards Where removes duplicated navigation messages for a satellite keeping the first occurrence of the navigation message. The navigation record with the transmission time closest before a given observation epoch is chosen.

A Galileo navigation data record is only valid for 4 hours after time of epoch and is updated every 10 minutes to 3 hours as described in Appendix C.4.4.1 in Galileo-OS-SDD [1]. Observation epochs are excluded if they exceed the validity length of the navigation record. In addition only healthy Galileo satellites are used in the analysis.

Results

We have carried out a SISRE analysis with software package Where using data from January 1st until June 30th 2018. The results can be seen in the Figures 1, 2 and 3.

Figure 1 shows the global averaged SISRE for all Galileo satellites for the signal combination E1/E5a using the F/NAV navigation message. The determined SISRE RMS is 17 cm for the half year time period and over all Galileo satellites. This is significantly better than for E1 and E1/E5 signal combination based on I/NAV navigation message (see Table 2).

Figure 2 illustrates the SISRE RMS for the Galileo satellites. The SISRE RMS solution is mostly driven by errors, clock and bias errors contribute only slightly to the complete SISRE solution. This can be explained by the fact that Galileo uses highly stable clocks and short update rates for the broadcast ephemera [2].

Figure 3 represents the SISRE 95th percentiles for single- and dual-frequency users on a monthly basis. Table 2 shows the corresponding numbers for the complete half year period. The Where solution indicates differences up to few centimeters between the E1, E1/5a and E1/E5a signal combinations, whereas the GSC solution based on the Galileo quarterly performance reports [1, 2] does not show any significant differences. In addition the Where half year SISRE 95th percentiles are lower in comparison to GSC solution, especially with less than 10 cm for a E1/5a user by applying F/NAV messages.

Summary

The first results of SISRE analysis with the software package Where are comparable to other studies (e.g. [1, 2] or [5]) with a global average SISRE RMS up to 20 cm and a monthly 95th percentile of 25–40 cm for the Galileo system. Further validation is needed to identify the cause of the differences between the Galileo and GSC solution. In addition the quality of the input data has to be improved, which includes the used IGS broadcast, precision ephemerides and precise PCOs. It is important to ensure the correct detection of Galileo anomalies related to the control and satellite segment.

Table 2 shows the SISRE RMS and 95th percentile results for Where and GSC [1, 2] solution are given for the complete Galileo satellite constellation and the period January 1st until June 30th 2018. The average is determined of the GSC monthly 95th percentile given in [1] and [2].

References


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Table 1: Input data used for SISRE analysis

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