GALILEO
HIGH ACCURACY SERVICE DAYS
Evaluation of Galileo High Accuracy Service (HAS) with Android Smartphone Data

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Galileo HAS Days Conference
Outline

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   b. Accuracy in Android phones
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1. Overview

Galileo HAS is available via the Internet.
The largest use case for HAS is location in smartphones.

We want to evaluate:

- the accuracy of the corrections compared to DGNSS,
- the benefit of the corrections on GNSS positions in Android phones.

TLAs:
DGNSS Differential GNSS
GNSS Global Navigation Satellite Systems
HADG High Accuracy Data Generator
HAS High Accuracy Service

Source: www.gsc-europa.eu/galileo/services/galileo-high-accuracy-service-has
2. Tests, objectives

Objectives:

a) evaluate HAS SSR corrections in the USA
   Availability

a) compare HAS SSR corrections to DGNSS OSR corrections
   DGNSS OSR corrections = geo range - measured pseudorange at a reference station
   Components of SSR corrections: (satellite orbit + clock + bias) + iono + tropo

a) evaluate HAS benefit on Android phone positions

a) robust method of implementation of HAS IDD (incl: unit tests)

TLAs:
SSR State Space Representation
OSR Observation Space Representation
HAS availability

Three dimensions of availability:

1. Official service area
2. Ground station visibility from a satellite
3. HAS correction availability per satellite
Official HAS Service Area

Source: GALILEO HIGH ACCURACY SERVICE, SERVICE DEFINITION DOCUMENT, (HAS SDD) Issue 1.0, January 2023
HAS coverage from the pov of a satellite (updated May 2023)

TLAs:
DoC: Depth of Coverage

Ground traces of visible satellites, showing HAS gaps

horizon cut-off from test site
2. Tests, HAS vs DGNSS

Methodology:

- IGS Reference station at Stanford, California.
- DGNSS OSR corrections from Ref station
- SSR Corrections from: HAS + Iono + Tropo calculated for the reference station position
- $\nabla$, single diff, with highest satellite. For each (1) and (2). Removes ref station clock error.
- Plot and compare $\nabla$ values.
OSR and SSR corrections

OSR and SSR corrections compared.
\( \nabla \text{OSR} \) to remove the reference station clock error
\( \nabla \text{SSR} \) for a valid comparison with \( \nabla \text{OSR} \)

Note: SSR matches OSR closely

TLAs:
- **OSR**: Observation Space Representation
- **\( \nabla \text{OSR} \)**: Single-differenced OSR
- **SSR**: State Space Representation
- **\( \nabla \text{SSR} \)**: Single-differenced SSR
SSR: HAS, delta_iono, and delta_tropo corrections

Clock & orbit: corrections to ephemeris position and clock:
(broadcast error $a_0, a_1, a_2$, + group delay + relativistic offset)

Iono: corrections to broadcast iono model

Tropo: corrections to nominal tropo delay

“Delta-Layer Cake”
3. Tests, Accuracy in Android Phones

Methodology:

- Log raw GNSS measurements with phone at a surveyed point
- Apply DGNSS OSR Corrections
- Apply HAS SSR Corrections
- Compare positions computed: with no corrections, with HAS SSR, with OSR

- Repeat with driving tests, using RTK SPAN + IMU system for ground truth
Test area

Pixel 6a phone, with raw GNSS measurements (code and carrier)

Phone Test Location

IGS Reference Station

Phone on ground, to avoid multipath

Position surveyed previously
Position results:

Stand-alone

mean 0.839 m
50% 0.956 m
95% 1.135 m

HAS SSR

mean 0.516 m
50% 0.457 m
95% 0.984 m

DGNSS OSR

mean 0.434 m
50% 0.408 m
95% 0.650 m

horizontal 2d error statistics

Comparative results, each using the same set of GPS & Galileo satellites (L1)

Pixel 6a phone
Drive test, Samsung Galaxy A-series
Drive Test Results, 2d position histograms, and cross-track stats.

Stand-alone

mean 3.279 m
50%  3.371 m
95%  5.671 m

HAS SSR

mean 1.766 m
50%  1.615 m
95%  3.633 m

DGNSS OSR

mean 1.040 m
50%  0.831 m
95%  2.572 m

Comparative results, each using the same set of GPS & Galileo satellites (L1)
Samsung Galaxy A51 phone
### Drive Test Results, all four phones

#### Cross-track errors (50%, meters), Samsung Galaxy A series

<table>
<thead>
<tr>
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<th>A31</th>
<th>A6</th>
<th>A51</th>
<th>A50</th>
<th>Average</th>
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<tr>
<td>Stand-alone</td>
<td>3.43</td>
<td>2.32</td>
<td>3.37</td>
<td>2.97</td>
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<td>HAS SSR</td>
<td>2.33</td>
<td>1.14</td>
<td>1.62</td>
<td>1.98</td>
<td>1.77</td>
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<td>DGNSS OSR</td>
<td>1.34</td>
<td>0.80</td>
<td>0.83</td>
<td>1.91</td>
<td>1.22</td>
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#### Cross-track errors (95%, meters), Samsung Galaxy A series

<table>
<thead>
<tr>
<th></th>
<th>A31</th>
<th>A6</th>
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<tr>
<td>Stand-alone</td>
<td>6.69</td>
<td>3.81</td>
<td>5.67</td>
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<td>HAS SSR</td>
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<td>2.86</td>
<td>3.63</td>
<td>7.76</td>
<td>4.82</td>
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<tr>
<td>DGNSS OSR</td>
<td>4.09</td>
<td>1.98</td>
<td>2.57</td>
<td>8.08</td>
<td>4.18</td>
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Comparative results, each using the same set of GPS & Galileo satellites (L1)

Samsung Galaxy A-series phones
4. Interesting Observations
magnitude of orbit corrections

<table>
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<th>HAS orbit corrections over 24 hours (m)</th>
<th>GAL</th>
<th>GPS</th>
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<tbody>
<tr>
<td>rms</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>50%</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>95%</td>
<td>•</td>
<td>•</td>
</tr>
</tbody>
</table>
5. Summary

- HAS SSR shows promise for submeter accuracy in phones
  - Even with L1-only receivers, and …
  - at the “edge of the HAS universe” in western California
  - More tests needed for a definitive conclusion

- The dominant error components in the SSR are iono and tropo
  - Good iono data and tropo models are essential
  - HAS orbit and clock corrections are often > 1m and cannot be ignored

- There are geographical limits to HAS
  - East Asia and Oceania out of bounds
  - West coast of North America on the edge, but HAS is still useful
Important outcome of tests and EC/EUSPA collaboration:

Unit test needed for HAS corrections.

e.g. How does the code bias work:

- code bias replaces the broadcast group delays (HAS IDD ICD)
- broadcast group delay subtracts from the clock corrections (OS SIS ICD)
- group delay is intended differently for single and dual frequency receivers (OS SIS ICD)
- code bias applies to pseudo-range, group-delay applies to satellite clock (satellite clock smaller ⇔ pr bigger)

+ Murphy’s law …

=> chance of an error in coding this ~ 100%

3.3.4 Code biases

The satellite code biases $\Delta d_j$ (DF383, [5]) provide the offset to be applied to the individual signals (DF382 for Galileo satellites [5], DF380 for GPS satellites [5]) targeted by each bias. The user pseudorange observation $P_{0,j}$ for satellite $s$ and signal $j$ must be corrected by adding the corresponding bias $\Delta d_j$ to generate the corrected pseudorange observation $\overline{P}_{0,j}$ as per Eq. 10.

$$\overline{P}_{0,j} = P_{0,j} + \Delta d_j$$  \quad \text{Eq. 10}

The satellite code bias $\Delta d_j$ replaces the Broadcast Group Delays (BGDs) and Timing Group Delays (TGDs) provided in the broadcast navigation messages as per [3] and [7], which must not be applied to the pseudorange observation.

A single frequency user receiver processing pseudo-ranges from the frequency $f_1$ applies the following correction to the SV clock correction $\Delta \tau_{f_1}$ which is defined in paragraph 5.1.4

$$\Delta \tau_{f_1}(f_1) = \Delta \tau_{f_1}(f_1, f_2) - BGD(f_1, f_2)$$  \quad \text{Eq. 15}
Thank you!

Contributors

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¡THANK YOU!

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