Enabling Multi-Constellation Advanced Receiver Autonomous Integrity Monitoring (ARAIM)

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ARAIM Overview

- **GNSS Evolutionary Architecture Study (GEAS) Phase II Report Recommendations**
  - Development of dual frequency SBAS
  - Development of architectures and algorithms for Advanced Receiver Autonomous Integrity Monitoring (ARAIM), based on
  - Dual frequency ARNS (L1 and L5) signals
  - At least two independent GNSS core constellations for civil aviation.

- **GEAS determined ARAIM could enable worldwide LPV-200 performance, provided:**
  - Measurement redundancy and geometric diversity was assured
  - Results based on assumed knowledge of specific “parameters” for the core GNSS constellations

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ARAIM Results for 30 SVs & URA = .5 m

ARAIM currently predicated upon a user update rate of ~ 1hour

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Performance Parameters for ARAIM

- ARAIM depends on GNSS specific constellation performance parameters:
  1. Bounding of fault-free clock and ephemeris error distributions
  2. Prior probability of SV faults
  3. Independence of faults between core constellations.

- ARAIM users receive an integrity support message (ISM)
  - GNSS service provider provides ISM to aviation users directly
  - ARAIM ISM generated by civil aviation authority with independent monitoring capability and broadcast to users
Integrity Support Message (ISM)

Dual frequency open service
Fast single faults & most multiple faults on the aircraft

Nation-state approves ARAIM on dispatch

GNSS #1
Ground Control

ISM for GNSS #1

GNSS #2
Ground Control

ISM for GNSS #2
**Example: Worldwide coverage results**

<table>
<thead>
<tr>
<th>$P_{\text{sat}}/\text{URA}$</th>
<th>.5 m</th>
<th>1 m</th>
<th>1.5 m</th>
<th>2 m</th>
<th>3 m</th>
<th>3.5 m</th>
<th>4 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-5}$</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>42.9%</td>
<td>3.4%</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>99.6%</td>
<td>6.6%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Less accuracy (URA)

Less constellation reliability

- $P_{\text{const}} < 10^{-8}$
- $P_{\text{const}} = 10^{-6}$
- $P_{\text{const}} = 10^{-4}$

GPS 27 + Galileo 27

$P_{\text{sat}} = $ Prob. of satellite fault

$P_{\text{const}} = $ Prob. of constellation fault

$b_{\text{max}} = 0.75$ m

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Parameters Needed From GNSS Provider

- User Range Accuracy → ‘URA’
  - Standard deviation of the overbounding Normal distribution for clock and ephemeris errors

- Bias parameter → ‘b_{max}’
  - May be needed to bound potential non-zero mean error distributions

- Fault state probability (fault-rate×time-to-notify) → ‘P_{sat}’
  - Needed for faults that are independent between satellites

- Probability of constellation-wide fault → ‘P_{const}’
  - For multiple faults that are not independent between satellites
    - Example is Earth Orientation Parameter (EOP) fault undetected by GNSS ground system

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Summary

• Four basic parameters are needed to enable ARAIM integrity:
  – URA and $b_{\text{max}}$ to describe nominal performance of clock and ephemeris
  – Prior probability of satellite fault
  – Prior probability of constellation failure

• A common understanding of these parameters must be developed and agreed upon by the service providers for interoperability

• ISM is a mechanism to deliver these parameters to users

• Delivery of ISM could be from multiple sources

• GNSS service providers need to include these parameters in Performance Standards