Using SBAS to Enhance GBAS User Availability: Results and Extensions

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Motivation

• GBAS availability is limited by the “geometry screening” implemented to mitigate hypothetical worst-case ionospheric anomalies.
  – Ground screening has severe impact on CAT I LAAS.
  – Airborne screening used in GAST-D (for CAT III) remains driven by ionospheric threats.

• External information is the key to removing this constraint.

• Three approaches have been envisioned:
  1) Use of certified SBAS where it now or will exist
  2) Use of uncertified “COTS” monitoring networks
  3) Use of space weather forecasts and “nowcasts”
Severe Ionospheric Anomaly in CONUS on 20 November 2003

20:15 UT

21:00 UT
Time Variation of Ionospheric Delay on 20 November 2003

Data from 7 CORS stations in N. Ohio and S. Michigan
Resulting Ionospheric Anomaly Threat Model for CONUS

Linear bound:
\[ y_{bnd} \text{ (mm/km)} = 375 + \frac{50(e\text{I}-15)}{50} \]

Also bounds on:
- Front speed wrt. ground: \( \leq 750 \text{ m/s} \)
- Front width: 25 – 200 km
- Total differential delay \( \leq 50 \text{ m} \)
Worst-Case Impact on CAT I GBAS

Maximum Ionospheric Error in Vertical (MIEV) at Memphis (24-Satellite SPS-Standard GPS Constellation)
Parameter Inflation Required to Remove Unsafe Subset Geometries

Use $\sigma_{pr_{\text{gnd}}}$/P-value inflation algorithm described in {Ramakrishnan, et al, ION NTM 2008}

10-meter VAL
SBAS to Augment GBAS (1): Today’s SBAS Coverage

Source: T. Walter, et al, ION ITM 2010

Availability as a function of user location

SBAS LPV Availability

Availability with VAL = 35, HAL = 40, Coverage(99%) = 7.54%
SBAS to Augment GBAS (2): Future SBAS Network Expansion

Source: T. Walter, et al, ION ITM 2010
SBAS to Augment GBAS (3):
SBAS by 2025 (GPS L1-L5 w/Expansion)

Source: T. Walter, et al. ION ITM 2010

SBAS LPV Availability

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 67.57%
<table>
<thead>
<tr>
<th>GIVE Value</th>
<th>GIVE Integer</th>
<th>GBAS Class.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 6.0 m</td>
<td>0 – 12</td>
<td>Good</td>
<td>WAAS verifies that no threat is present here.</td>
</tr>
<tr>
<td>15.0 m</td>
<td>13</td>
<td>Not Observed</td>
<td>WAAS observations are too limited to confirm that no threat exists.</td>
</tr>
<tr>
<td>45.0 m</td>
<td>14</td>
<td>Bad</td>
<td>WAAS detects a nearby ionosphere storm – possible threat.</td>
</tr>
<tr>
<td>Not Monitored</td>
<td>15</td>
<td>Not Observed</td>
<td>WAAS observations are too limited to provide any iono. assurance.</td>
</tr>
</tbody>
</table>
GIVE Method Case 1:
All IGP’s are “Good”

\[ \text{GIVE}_2 = 6.0\, \text{m} \]

\[ \text{GIVE}_3 = 3.6\, \text{m} \]

\[ \text{GIVE}_4 = 2.7\, \text{m} \]

GBAS IPP for SV\( j \)

\[ \text{Long}_1 \]

\[ \text{Lat}_1 + 5^\circ \]

\[ \text{Long}_{1} + 5^\circ \]
GIVE Method Case 2: One IGP is “Not Observed”

GIVE\textsubscript{2} = “Not Monitored”

GIVE\textsubscript{1} = 6.0 m

GBAS IPP for SV \textit{j}

GIVE\textsubscript{3} = 4.5 m

GIVE\textsubscript{4} = 3.0 m
GIVE Method Cases 3 and 4: One IGP is Either “Neutral” or “Bad”

“Neutral” Case

- $GIVE_1 = 6.0 \text{ m}$
- $GIVE_4 = 3.0 \text{ m}$
- $Lat_1$
- $Long_1$
- $Lat_1 + 5^\circ$

“Bad” Case

- $GIVE_2 = 15.0 \text{ m}$
- $GIVE_3 = 4.5 \text{ m}$
- $Lat_1 + 5^\circ$
- $GIVE_2 = 4.5 \text{ m}$ (or 15.0 m or “Not Monitored”)
- $GIVE_1 = 6.0 \text{ m}$
- $GIVE_4 = 3.0 \text{ m}$
- $Lat_1$
- $Long_1$
- $Long_1 + 5^\circ$
Validation via UIVE at Local Area Monitor (LAM) Site


- UIVE > 13 m threshold violated (briefly) ≈ 0.6 % of the time
- Proposed rules for GBAS are somewhat stricter
  - Need to retain geometry screening as a backup mode
**SBAS UDRE for Clock/Ephemeris Monitoring**

<table>
<thead>
<tr>
<th>UDRE Value</th>
<th>UDRE Integer</th>
<th>GBAS Class.</th>
<th>Ephemeris MDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 50.0 m</td>
<td>0 – 12</td>
<td>Good</td>
<td>500 m</td>
</tr>
<tr>
<td>150.0 m</td>
<td>13</td>
<td>OK</td>
<td>1500 m</td>
</tr>
<tr>
<td>Not Monitored</td>
<td>14</td>
<td>Neutral</td>
<td>GBAS value (≈ 2700 m)</td>
</tr>
<tr>
<td>Do Not Use</td>
<td>15</td>
<td>Do Not Use</td>
<td>Exclude from Use</td>
</tr>
</tbody>
</table>

Ensures that ephemeris threat never limits CAT I availability.
Recent Work of Dr. R. Eric Phelts at Stanford

Maximum of 4 SDM metrics used to demonstrate lack of signal deformation

Use of External Information in GBAS

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Alternatives to SBAS

• Despite expected growth of SBAS, some GBAS sites will lie outside good SBAS coverage
  – Also, no assurance that all SBAS systems will satisfy GIVE and UDRE performance assumptions.

• Two alternatives are worth considering:
  – Running SBAS-like algorithms on outputs of existing, “uncertified” receiver networks
  – Using space weather products now being developed:
    » “nowcasts” of the real-time situation
    » 3 – 6 hour (?) look-ahead forecasts

• Both of these alternatives require replacements for high-integrity SBAS processors and datalinks
Enhancements of existing ground receiver networks can substitute for SBAS in specific regions.
Concerns with Use of External Information (1)

• The original “benefits case” for GBAS assumes that each site operates independently, as do ILS and MLS.
  – GBAS precision approaches are “ILS-lookalike”.

• Therefore, GBAS cannot rely upon external information.
  – GBAS-only methods run in the background at all times.
  – For example, when SBAS cannot guarantee that no threat exists, existing GBAS algorithms still provide required integrity assurance, but with reduced availability.

• Even if GBAS can operate without external information, the FAA is hesitant to rely on it to meet advertised performance benchmarks.
Concerns with Use of External Information (2)

- Non-aviation substitutes for SBAS are technically feasible but require guarantees that information provided is “safe” to civil aviation standards.

- Existing receiver networks must be “certifiable” without requiring “SBAS” levels of coding and redundancy (otherwise, not cost-effective).

- Beyond network outputs, automated data-transfer mechanism to each GBAS site must also be certified.
  - NextGen mission statement highlights the future importance and data-sharing networks, but most ATM information has less direct safety impact (or does it?)
  - Understanding and providing this capability should be part of NextGen/SESAR/etc. and should not be limited to GNSS.
Summary

• The use of external information is the most cost-effective near-term way to enhance GBAS availability.
  – Guarantee absence of ionospheric anomalies
    » Enhance precision approach availability
    » Enable other uses of GBAS (“DCPS”)
  – Monitor GNSS satellites to much tighter tolerances

• SBAS is the most convenient way to obtain this information
  – Algorithms and datalinks are already certified
  – Information delivered in timely manner on L1 frequency

• Where SBAS is not suitable, alternatives exist, but new safety certification is needed.
Questions?

• Thank you for your attention。
  ご清聴は、ありがとうございました。

• Questions are welcome!
  質問だったら、遠慮しないで、英語にも日本語にも伺ってください。