Different Shades of SBAS

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Purpose

1. Tease out similarities and difference in their augmentation capabilities
   a. SBAS for aviation
   b. “non aviation” SBAS

2. Present an overview of SBAS options for augmented GNSS services in Australia and New Zealand

Note:
SBAS – Satellite Based Augmentation System
What is SBAS?

SBAS: Satellite-based Augmentation System

SBAS is a civil aviation safety-critical system that supports wide-area or regional augmentation through the use of geostationary satellites.

Keywords:

(1) Civil aviation safety-critical system, ICAO SARPs

(2) Augmentation

SBAS enhance existing GNSS by mainly providing \textit{integrity} and improving \textit{accuracy}.

ICAO - International Civil Aviation Organisation
SARPs - SBAS Standards and Recommended Practices
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SBAS for Aviation

SBAS transmits (a) integrity, (b) ranging information, and (c) correction messages:

(a) **Integrity** is enhanced by sending alerts to users to not track the failed satellites identified as having large signal errors.

(b) **Signal availability** is improved as the SBAS satellite transmits additional L1 ranging signal.

(c) **Accuracy** is enhanced through the transmission of wide-area corrections for range errors, such as satellite orbits, clocks, and improved ionospheric information.
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SBAS service is available to all users.

The majority of mass market receivers have SBAS capability.
Existing SBAS Systems

Operational
Certified for precision approach (2016)
- WAAS (US)
- EGNOS (EU)

Limited to Non-precision approach
- MSAS (Japan)
- GAGAN (India)

Still to be certified or under development
- SDCM (Russia)
- Beidou SBAS (China)
- KASS (South Korea)
- SBAS Africa
- Other systems in feasibility phase

(GENQ Inc, 2015)
Integrity (Vertical) margins as maximum Vertical Safety index map (maximum ratio between the vertical user error and the vertical user protection level).

Accuracy (Vertical) map, 95% Vertical Position Error in metres.

(ESA Navipedia, 2011)
Aviation SBAS for Australia

According to a white paper produced by the Australian Space Industry Innovation Council in 2011* …..

Australia could consider a SBAS capability that is:

- Solely owned and operated by Australia
- An extension of other existing SBAS
- A global SBAS model, either implemented as part of a government or commercial arrangement

Augmented GNSS using Satellite Technology

“Non-aviation” SBAS

Not compliant with aviation requirement:

- Differences in data message structures
- Different frequencies used for transmission of corrections
- Absence of the extra ranging signals from the GEO satellites
- Missing integrity data and monitoring

differ predominantly in positioning accuracy and targeted applications
Positioning Accuracy

![Diagram showing positioning accuracy for different technologies: DGNSS, SBAS, PPP, and RTK. The y-axis represents accuracy in meters (10 m, 1 m, 10 cm, 1 cm), and the x-axis represents baseline in kilometers (10 km, 100 km, 1000 km, 1000 km Worldwide). The diagram illustrates the comparative accuracy of each technology over different baselines.](image)

(IGNSS2016@UNSW, Sydney 12 (NovAtel Inc, 2015))
Commercial “Non-aviation” SBAS

<table>
<thead>
<tr>
<th>Company</th>
<th>Services</th>
<th>Accuracy (horizontal)</th>
<th>Convergence time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>OmniSTAR</td>
<td>OmniSTAR HP</td>
<td>5–10 cm (95 %)</td>
<td>&lt;45 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OmniSTAR G2</td>
<td>8–10 cm</td>
<td>&lt;20 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OmniSTAR XP</td>
<td>8–10 cm</td>
<td>&lt;45 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OmniSTAR VBS</td>
<td>&lt;1 m (95 %)</td>
<td>&lt;1 min</td>
<td>Pseudo-range corrections</td>
</tr>
<tr>
<td>Trimble</td>
<td>CenterPoint RTX</td>
<td>&lt;4 cm (95 %)</td>
<td>&lt;5 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RangePoint RTX</td>
<td>&lt;50 cm (95 %)</td>
<td>&lt;5 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ViewPoint RTX</td>
<td>&lt;1 m (95 %)</td>
<td>&lt;5 min</td>
<td></td>
</tr>
<tr>
<td>Fugro</td>
<td>Starfix.G2+</td>
<td>3 cm</td>
<td>Not provided</td>
<td>Uses ambiguity resolution</td>
</tr>
<tr>
<td></td>
<td>Starfix.G4</td>
<td>10 cm</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starfix.G2</td>
<td>10 cm</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starfix.XP2</td>
<td>10 cm</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starfix.HP</td>
<td>10 cm (95 %)</td>
<td>Not provided</td>
<td>Third party corrections</td>
</tr>
<tr>
<td></td>
<td>Starfix.L1</td>
<td>&lt;1.5 m (95 %)</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td>NavCom</td>
<td>StarFire</td>
<td>&lt;5 cm (68 %)</td>
<td>Not provided</td>
<td>StarFire algorithms</td>
</tr>
<tr>
<td></td>
<td>C-Nav C2</td>
<td>8 cm (95 %)</td>
<td>Not provided</td>
<td>StarFire algorithms</td>
</tr>
<tr>
<td></td>
<td>C-Nav C1</td>
<td>15 cm (95 %)</td>
<td>Not provided</td>
<td></td>
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<tr>
<td>Veripos</td>
<td>Apex</td>
<td>&lt;5 cm (95 %)</td>
<td>Not provided</td>
<td>Own reference station network and calculations</td>
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<tr>
<td></td>
<td>Apex</td>
<td>&lt;5 cm (95 %)</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultra 2</td>
<td>&lt;10 cm (95 %)</td>
<td>Not provided</td>
<td>JPL reference station network and calculations</td>
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<td></td>
<td>Ultra</td>
<td>&lt;10 cm (95 %)</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard 2</td>
<td>&lt;1 m (95 %)</td>
<td>Not provided</td>
<td>Pseudo-range corrections</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>&lt;1 m (95 %)</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td>TerraStar</td>
<td>TerraStar-C</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Uses ambiguity resolution</td>
</tr>
<tr>
<td></td>
<td>TerraStar-D</td>
<td>&lt;10 cm (95 %)</td>
<td>Not provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TerraStar-M</td>
<td>&lt;1 m (95 %)</td>
<td>Not provided</td>
<td>Pseudo-range corrections</td>
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<tr>
<td>Novatel</td>
<td>CORRECT (PPP)</td>
<td>4 cm</td>
<td>20–40 min</td>
<td>TerraStar-C corrections</td>
</tr>
<tr>
<td>Hemisphere</td>
<td>Atlas</td>
<td>4 cm</td>
<td>10–40 min</td>
<td></td>
</tr>
</tbody>
</table>

Note that not all companies list the accuracy confidence level. Some mention a 1-sigma level (corresponding to 68 %), and others mention a 95 % confidence (corresponding to 2-sigma). The accuracy values shown in this table are the accuracies reported by the companies and do not refer to values resulting from independent research.
Dual-frequency Multi-constellation Aviation SBAS

Dual-frequency GNSS operation:

• Increases SBAS availability and performance as it will be robust against ionospheric gradients
• Improves robustness against unintentional interference
• Support multi-constellation

Development:

• WAAS Development Phase IV -Dual Frequency Operations. Planned for 2014-2028 (2044)
• GSA is conducting activities to support next generation EGNOS
Dual-frequency GPS-only SBAS

Dual-frequency WAAS, EGNOS, MSAS, GAGAN and SDCM coverage (GPS-only)

(Walter et al. 2010)
Dual-frequency GPS-only SBAS

Hypothetical expansion of ground stations for WAAS, EGNOS and MSAS into the southern hemisphere

Dual-frequency GPS-only SBAS

(Walter et al. 2010)
Dual-frequency Multi-constellation SBAS

Current ground stations.
GPS+Galileo
Dual-frequency WAAS, EGNOS, MSAS, GAGAN and SDCM coverage

Expansion of ground stations in the southern hemisphere

(Walter et al. 2010)
Next Generation GNSS/RNSS

- New augmentation signals with data transmission channels: SBAS, DGNSS, PPP
- MEO and IGSO satellites, in addition to GEO satellites
Galileo

Galileo Navigation Signals: Overview

E5a Signal:
- Data+Pilot
- Mod.: BPSK
- $R_p=10.23$ Mcps
- $R_s=50$ sps
- Open Services

E5b Signal:
- Data+Pilot
- Mod.: BPSK
- $R_p=5.115$ Mcps
- $R_s=250$ sps
- Open Services

E6-A Signal:
- Mod.: BOCc(15,2.5)
- Public Regulated Service

E6-B/C Signal:
- Data+Pilot
- Mod.: BPSK Overlay
- $R_p=1000$ sps
- Commercial Service

E1-A Signal:
- Mod.: BOCc(15,2.5)
- Public Regulated Service

E1-B/C Signal:
- Data+Pilot
- Mod.: CBOC Overlay
- Power Ratio 10/1
- $R_p=1.023$ Mcps
- $R_s=250$ sps
- Open Services

★ Aligned and interoperable with future GPS (modernized L1C and L5) signals, by carrier frequency and modulation

(GSA, 2015)
### Positioning Signal of QZSS

Not only positioning complementation signal, but satellite orbit, time, and ionosphere correction information will be also transmitted as augment information.

<table>
<thead>
<tr>
<th></th>
<th>1st Satellite</th>
<th>2nd–4th Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QZO</td>
<td>QZO</td>
</tr>
<tr>
<td><strong>L1C/A</strong></td>
<td>Positioning</td>
<td>complement GPS</td>
</tr>
<tr>
<td><strong>L1C</strong></td>
<td>Positioning</td>
<td>complement GPS</td>
</tr>
<tr>
<td><strong>L1S</strong></td>
<td>1575.42 MHz</td>
<td>Augmentation (SLAS)</td>
</tr>
<tr>
<td></td>
<td>Message Service</td>
<td></td>
</tr>
<tr>
<td><strong>L2C</strong></td>
<td>1227.60 MHz</td>
<td>Positioning</td>
</tr>
<tr>
<td><strong>L5</strong></td>
<td>1176.45 MHz</td>
<td>Positioning</td>
</tr>
<tr>
<td><strong>L5S</strong></td>
<td>1176.45 MHz</td>
<td>Augmentation</td>
</tr>
<tr>
<td><strong>L6</strong></td>
<td>1278.75 MHz</td>
<td>Augmentation</td>
</tr>
<tr>
<td><strong>L1Sb</strong></td>
<td>1575.42 MHz</td>
<td>Augmentation</td>
</tr>
</tbody>
</table>

SBAS Service will be available from the beginning of 2020’s.

(QSS Inc., 2015)
Summary

• Aviation SBAS:
  – Civil aviation safety-critical system, ICAO SARPs
  – Enhance existing GNSS by providing integrity and improving accuracy

• Non-aviation SBAS:
  – Support numerous GNSS PNT applications
  – Wide-area DGNSS and PPP techniques
  – Not ICAO compliant

• Dual-frequency multi-constellation SBAS brings improved performance, e.g., robust against ionosphere, coverage, interference

• Next generation GNSS/RNSS satellites with augmentation capabilities
Food for Thoughts

SBAS consideration for Australia

1. Which SBAS? For aviation or non-aviation applications?
   • Different users’ requirements: accuracy, integrity, availability and continuity. E.g., C-ITS, 1m 95%??

2. Our own SBAS, or can we cooperate?
   • Existing SBAS and/or next generation GNSS/RNSS

3. What services to provide? SBAS, DGNSS, PPP and/or PPP-RTK?

4. What are the roles of Government and Industry?

5. Would “PPP-like” satellite corrections be provided for free in the future by GNSS/RNSS satellites?
   • “Selective unavailability”