Enhancement of Augmentation Signal Availability by SBAS Implementation with the QZSS Constellation

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Introduction

- SBAS: Satellite-Based Augmentation System
  - International standard augmentation system.
    - Transmits Augmentation information from the SBAS satellite.
    - Augments GNSS in terms of integrity and accuracy.
    - Current standard: Single-frequency SBAS on L1 transmitted by GEO.
    - US WAAS, Japanese MSAS, European EGNOS, Indian GAGAN.

- DFMC SBAS: The Second Generation SBAS
  - Dual-Frequency Multi-Constellation SBAS.
  - ENRI has been conducting DFMC SBAS experiment via QZSS L5S signal.

- Innovation: Augmentation Service by IGSO Satellites
  - DFMC SBAS could be transmitted by IGSO SBAS satellite.
    - Including QZSS IGSO.
    - Possible solution for applications where GEO signal is likely blocked.
    - Enables SBAS service independent of the latitude of the service area by combination of dual-frequency operation and IGSO transmission.
**SBAS Architecture**

- Monitors consistency of GNSS signals on the ground.
- Transmits differential correction and integrity information via SBAS satellite.

**Limitation:** The current standard (L1 SBAS) allows transmission only from GEO.

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**NAVCANADA Reports**

- CRJ circuits at Stephenville, NL (48.6N 58.6W).
- GEO signal is likely blocked due to attitude (pitching and banking).

Galaxy 15 GEO (133W) at Az 258° El 1.5°

Reported by Steve Bellingham of NAVCANADA at SBAS IWG/32 in Seoul.
NAVCANADA Reports

SLIDE 4

• Dash-8 arrival at Iqaluit, NU (63.7N 68.5W).
• They have also reported similar situation for departure.

Reported by Steve Bellingham of NAVCANADA at SBAS IWG/32 in Seoul

Galaxy 15 GEO (133W)
at Az 247° El 2.3°

SLIDE 5

Solution: Usage of IGSO

• DFMC SBAS could be transmitted by non-GEO satellites like QZSS IGSO.
• Improves availability of augmentation signals where GEO signal is blocked.
  - Arctic/Nordic regions, mountain area, urban canyon,…
  - Navigating Arctic routes and precise positioning for resource exploration.
  - Note DFMC SBAS is not influenced by ionosphere even in Equatorial regions.
  - Seamless service from Equator to Poles, mountain to urban canyons…

Galaxy 15 GEO (133W) at Az 247° El 2.3°

Reported by Steve Bellingham of NAVCANADA at SBAS IWG/32 in Seoul

They have also reported similar situation for departure.
Visibility from Nordic Region

- Elevation angles computed from QZS-1/2/4 almanacs.
- QZSS IGSO satellites are visible in Nordic region; Elevation is higher than EGNOS GEO at some location.

Visibility from Alaska

- Elevation angles computed from QZS-1/2/4 almanacs.
- QZSS IGSO satellites are visible in Alaska region; Could transmit signals always from higher elevation than WAAS GEO.
DFMC SBAS by IGSO Satellites

• The Current SBAS
  – Single-Frequency service transmitted by GEO.
    ➢ Limited availability in the low latitude regions due to the ionospheric activities.
    ➢ GEO signal is likely blocked for some applications.

• DFMC (Dual-Frequency Multi-Constellation) SBAS
  – The second generation SBAS following the current SBAS.
    ➢ Eliminates ionospheric effects thanks to dual-frequency operation.
      ◆ Robust navigation service everywhere in the coverage.
    ➢ Could be transmitted by non-GEO SBAS satellites like QZSS IGSO.
  – Standardization activities ongoing by the ICAO.

• New Feature: Transmission by Non-GEO SBAS
  – DFMC SBAS could be transmitted by non-GEO satellites like QZSS IGSO.
  – Improves availability of augmentation signals where GEO signal is blocked.

Status of Standardization

• ICAO (International Civil Aviation Organization) has been discussing DFMC SBAS standards.
  – NSP (Navigation Systems Panel) has prepared the technical baseline SARPS (standards and recommended practices).
  – Defined as L5 SBAS using L5 frequency.
    ➢ L5 SBAS will be added to the current SARPS defining L1 SBAS.
  – RF specification and message contents are almost fixed.
    ➢ Validation activities are ongoing.
    ➢ Allows Non-GEO SBAS transmission as well as other new capabilities.
  – Target: Adoption by End of 2020 (NSP/7 meeting).

• EUROCAE has discussed receiver specifications.
  – WG-62 is preparing MOPS (Minimum Operational Performance Standards) for DFMC SBAS receivers.
    ➢ GPS/Galileo-capable L1/L5 dual-frequency processing.
  – Processing non-GEO SBAS signals is defined and likely optional function.
Prototype DFMC SBAS

- Prototype DFMC SBAS Developed by Japan
  - The second generation SBAS following L1 SBAS.
    - Eliminates ionospheric effects thanks to dual-frequency operation.
      - Vertical guidance service everywhere in the coverage.
  - Electronic Navigation Research Institute, National Institute of Maritime, Port and Aviation Technology has developed the prototype.
    - GPS/GLONASS/Galileo/QZSS-capable dual-frequency SBAS.
    - Compliant with the draft standards of L5 SBAS being discussed at ICAO.
      - With 8-bit preamble and no Manchester encoding.
      - Helps validation activities ongoing at ICAO.

- DFMC SBAS Experiment has been Conducted with QZSS
  - The First L5 SBAS experiment with live L5 signal from the space.
    - Using QZSS L5S augmentation signal transmitted from QZS-2, -3, and -4.
  - Prototype DFMC SBAS is used for the experiment.
  - Began the experiment on 23 Aug. 2017 via L5S signal of QZS-2 IGSO.
    - Now transmitting from QZS-2/4 IGSO and QZS-3 GEO.

Experimental Configuration

- Supports DFMC
- Provides observation in real time
- Operates in real time
- Dual-Frequency
- Supports GPS, GLONASS, Galileo, and QZSS
- Uplink L5 SBAS message stream for transmission
Real Time Experiment

- Evaluation of L5 SBAS message generated in real time.
  - Supporting GPS, Galileo, and QZSS in L1/L5 dual-frequency mode.
  - Confirmed that L5 SBAS augments multi-constellation of GPS+Galileo+QZSS.

Monitor Stations
- GPS+Galileo+QZSS
- Dual Frequency (L1+L5)
- DFMC L5 SBAS
- Location: GEONET 950369 (Wakayama)
- Period: 2017/11/13 01:00 - 07:00 (6H)

Output Message Stream
- Clock/Orbit Correction
- Position Solution
- Satellites in Sky
- Galileo SV-8
- Monitored Satellites
- 5 GPS
- No GLONASS
- 7 Galileo
- 2 QZSS

Real Time Experiment
Long-Term Stability Test

- Evaluated long-term performance using archive data at GEONET 950369 Wakayama.
  - Prototype DFMC SBAS runs not in real time for this test.
- Confirmed stable performance for a year; Horizontal ~0.5m and Vertical ~1m.

Reception Trial in Prague

- Preliminary Action with GSA (European GNSS Agency)
  - The first trial to receive L5S signal in Europe.
  - Conducted on March 21-22 at the GSA HQ.
  - Will be followed by the trial in Nordic Region hopefully in this summer.
**Observed L5 Signals**

- Observation by JAVAD Rx: Many Galileo satellites are tracked.
- Observation by Furuno Rx: QZS-2 IGSO above 5 deg. elevation during night time in CET.

**L5S Signal Reception**

- QZS-2 L5S signal observed by Furuno Rx.
- 0 to 7 deg. elevation with C/N₀ of 30 to 45 dB-Hz.
- LSS message stream successfully decoded.
Decoding L5S Message Stream

Logging Decoded Messages
Decoded L5 SBAS Message

- QZS-2 L5S message stream successfully logged and decoded.
- Contains L5 SBAS message.
  - Confirms the message transmission only: The message has been generated based on domestic stations within Japanese territory.

Conclusion

- SBAS: International Standard Augmentation System
  - Augments GNSS in terms of integrity and accuracy.
  - The standardization of DFMC SBAS is ongoing by the ICAO.
    - Eliminates ionospheric effects thanks to dual-frequency operation.
    - Could be transmitted by non-GEO SBAS satellites like QZSS IGSO.
  - ENRI has been conducting the DFMC SBAS experiment by its own prototype via QZSS L5S signal; Recently reception trial in Prague.
- IGSO SBAS Concept
  - Possible solution for applications where GEO signal is likely blocked.
    - High latitude/polar regions, mountain area, urban canyon,…
    - Navigating Arctic routes and precise positioning for resource exploration.
  - Enables SBAS service independent of the latitude of the service area by combination of dual-frequency operation and IGSO transmission.
    - Discussions with the northland countries are welcome!
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