Algerian SBAS system based on ALCOMSAT-1: characteristics and preliminary performance tests

S. KAHLOUCHE(1), L. TABTI(1), A.B. BENBOUZID(2), F. OUTAMAZIRT(2)

(1) Centre of Space Techniques
(2) Centre of Exploitation of Satellite Communication Systems
Kahlouche@asal.dz; abbenbouzid@asal.dz
INTRODUCTION

GNSS (GPS, GLONASS, GALILEO, Beidou) : Positioning in a general terrestrial referential

NEEDS: GNSS applications developed in Algeria
- Isolated Localization (accuracy: \( dm < \sigma < m \))
- Geodesy (National network, Cadastral Network, Urban Networks, ..)
- Industrial Risks: Auscultation of Dams, Ponts, Tanks storage of GNL.....
- Public Works (Rocks, Rail Infrastructure. ...)
- Scientific applications: crustal deformations, atmospheric modelling (TEC), Climate Change (IVW),...
- Navigation: Terrestrial, Maritime, Aviation : positioning and navigation in real time (Position, Cap, Speed, ..)

PROBLEMS : Accuracy in Real Time insufficient + Integrity \( \Rightarrow \) Satellite Based Augmentation System (SBAS)

SBAS is an augmentation system that transmit the complementary information to correct errors of measurements to improve positioning performance and to ensure integrity.
Satellite Based augmentation systems: SBAS

→ Principal objectives:
  - Improve the **accuracy** of GNSS systems (differential correction message);
  - To inform users about GNSS malfunctions (integrity message)/ **integrity** is means providing the user information on the reliability of the GPS in the form of confidence levels and alarms in case of anomalies

→ SBAS can provide:
  - Responds to the needs of civil aviation by providing accurate positioning and integrity.
  - Approach and landing operations with Vertical guidance (**APV**).
  - Precision approach service

Service for EGNOS based procedure in Europe

30/11/2022

https://egnos-user-support.essp-sas.eu
Performances: ICAO Requirements

1. **Accuracy**: Calculated position/true position

2. **Integrity**:
   - Integrity risk
   - Maximum tolerable error
   - Time to alert

3. **Continuity**: Limit risk of losing the service unexpectedly

4. **Availability**: Fraction of time that one has accuracy + integrity + continuity

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HAL: Horizontal Alarm Limit

- **NPA**: HAL = 556 m, VAL = N/A
- **APV I**: HAL = 40 m, VAL = 50 m
- **LPV 200**: (HAL = 40 m, VAL = 35 m)
- **APV II**: HAL = 40 m, VAL = 20 m
- **Cat I**: HAL = 40 m, VAL = 12 m
Satellite-Based Augmentation Systems: SBAS

⇒ SBAS: geostationary satellites (2-3) + reference stations network

WAAS (United States)
EGNOS (Europe)
GAGAN (India)
SNAS (China)
SDCM (Russia)

SBAS for Africa & Indian Ocean (ASECNA-NIGCOMSAT-THALES)

Algerian SBAS: Alcomsat-1, launched in December 11, 2017 (PRN 148).
Contents

- Introduction (SBAS, ICAO Requirements........)
- AL-SBAS system
  - Alcomsat-1
  - Code PRN
  - Architecture and function of AL-SBAS
  - Messages transmitted by AL-SBAS
- Preliminary performance tests of AL-SBAS
  - Précision
  - Integrity
  - Ionospheric grid
- Conclusions & Perspectives
Alcomsat-1 communications satellite

Alcomsat-1 communications satellite was launching on December 11, 2017, and is located at 24.8° W in a geostationary orbit. The coverage of Alcomsat-1 includes whole Africa, South America and part of Europe.

Alcomsat-1 is equipped with 33 transponders, including L1 & L5 signals navigation augmentation, the other bands are Ku and Ka.
Alcomsat-1 satellite communication system

Alcomsat-1 satellite system control and operating engineers.
Alcomsat-1 services and applications

1- Broadcasting service
Ku Bande(BSS) : 9 transponders

2- Fix service
Ku Bande(FSS): 10 transponders

3- Fixed high bandwidth service
Ka Bande(FSS): 10 transponders

4 - SBAS service: L Bande (2 transponders)
- C1/L1 band (Tx : 6695.42 – 6699.42 MHz 
  Rx : 1573.42 – 1577.42 MHz)
- C5/L5 band (Tx : 6630.45 – 6650.45 MHz 
  Rx : 1166.45 – 1186.45 MHz)
AL-SBAS Code PRN for SBAS

AL-SBAS has been assigned by the U.S. Space Force PRN codes, namely PRN148: codes are required for the broadcast through the GEO satellites of the SBAS signal-in-space.

In October 2020, Nigerian SBAS (NSAS: Nigerian Satellite Augmentation System) exists with code PRN 147 (orbit slot at 42.5° E), but in June 2021 this code is assigned to ASECNA (orbit slots at 5° W and 45° E) with another code PRN 120.

### L1 C/A PRN Code Assignments

<table>
<thead>
<tr>
<th>PRN Code Number</th>
<th>G2 Delay (Chips)</th>
<th>Initial G2 Setting (Octal)</th>
<th>First 10 Chips (Octal)</th>
<th>PRN Allocations System (Satellite)</th>
<th>Orbital Slot</th>
<th>Effective Through (Month Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>145</td>
<td>211</td>
<td>1560</td>
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<tr>
<td>146</td>
<td>121</td>
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<td>1742</td>
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<td>---</td>
<td>---</td>
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<tr>
<td>147</td>
<td>118</td>
<td>0355</td>
<td>1422</td>
<td>ASECNA (A-SBAS)</td>
<td>5 W -45 E</td>
<td>Nov 2024</td>
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<tr>
<td>148</td>
<td>163</td>
<td>0335</td>
<td>1442</td>
<td>ASAL (ALCOMSAT-1)</td>
<td>24.8 W</td>
<td>Jan 2024</td>
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<tr>
<td>149</td>
<td>628</td>
<td>1254</td>
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<tr>
<td>150</td>
<td>853</td>
<td>1041</td>
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<td>---</td>
<td>May 2031</td>
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<tr>
<td>151</td>
<td>484</td>
<td>0142</td>
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<tr>
<td>152</td>
<td>289</td>
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<tr>
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<td>568</td>
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<td>---</td>
</tr>
<tr>
<td>158</td>
<td>904</td>
<td>1542</td>
<td>0235</td>
<td>Unallocated</td>
<td>---</td>
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</tbody>
</table>


PRN codes 120-158 are designated for use by SBASs compliant with ICAO Standards and Recommended Practices (SARPs)
Here are the PRN assignment for each SBAS system in the June 2021 version, these systems are included, although some are not currently operational (https://www.gps.gov/technical/prn-codes/L1-CA-PRN-code-assignments-2021-Jun.pdf):

<table>
<thead>
<tr>
<th>SBAS System</th>
<th>PRNs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASAL (Algeria) – Algerian Space Agency</td>
<td>PRN 148</td>
</tr>
<tr>
<td>ASECNA (Africa &amp; Indian Ocean) – Agency for Aerial Navigation Safety in Africa and Madagascar</td>
<td>PRN 120 and 147</td>
</tr>
<tr>
<td>EGNOS (Europe) – European Geostationary Navigation Overlay Service</td>
<td>PRN 121, 123, 126, 136, 150</td>
</tr>
<tr>
<td>BDSBAS (China) – BeiDou Satellite-Based Augmentation System</td>
<td>PRN 130, 143, 144</td>
</tr>
<tr>
<td>GAGAN (India) – GPS-Aided Geo-Augmented Navigation</td>
<td>PRN 127, 128, 132</td>
</tr>
<tr>
<td>KASS (Korea) – Korean Augmentation Satellite System</td>
<td>PRN 134</td>
</tr>
<tr>
<td>MSAS (Japan) – Michibiki Satellite Augmentation System</td>
<td>PRN 129, 137, 139</td>
</tr>
<tr>
<td>SDCM (Russia) – System of Differential Correction and Monitoring</td>
<td>PRN 125, 140, 141</td>
</tr>
<tr>
<td>SPAN (Australia and New Zealand) – Southern Positioning Augmentation Network (AUS-NZ)</td>
<td>PRN 122</td>
</tr>
<tr>
<td>WAAS (United States) – Wide Area Augmentation System</td>
<td>PRN 131, 133, 135, 138</td>
</tr>
</tbody>
</table>

Algeria through its Algerian Space Agency (ASAL) is developing ”The Algerian Satellite Augmentation System (AL-SBAS)” in collaboration with China (SSTC). The overall AL-SBAS service delivery strategy is to meet user needs with an incremental approach in terms of coverage and performance, while considering scalability to the next generations (Multi Frequency and Constellation).
Code PRN for SBAS

PRN codes 120-158 are designated for use by SBASs compliant with ICAO Standards and Recommended Practices (SARPs). Applicants requesting PRNs 120-158 must meet the following requirements (https://www.gps.gov/technical/prn-codes/).

1. **SBAS Service Provider ID.** The subject system must be recognized by the ICAO Navigation Systems Panel (NSP) as an Operational or Planned SBAS. The ICAO SBAS Service Provider ID must be indicated on the application.

2. **Letter from Civil Aviation Authority.** The applicant must submit a letter from the Civil Aviation Authority (CAA) or Aviation Safety Body confirming compliance with ICAO SARPs.

   **For Temporary assignments,** the letter must include the expected date of operational service for certified aviation. For Final assignments, the letter must include confirmation that the system is operational and certified for aviation.

**Note:** The requesting or endorsing CAA may reside in a different state from where the SBAS service provider is licensed in accordance with respective national regulations.
Architecture and function of AL-SBAS

AL-SBAS:
- 18 ground Reference Stations (RS),
- 03 Augmented Reference Stations (ARS),
- 01 Data Process Center (DPC),
- 01 Ground UpLink Station (GULS),
- Alcomsat-1 navigation transponders,
- User terminals.

The AL-SBAS system architecture is defined, and the preliminary design of the system is completed in compliance.
AL-SBAS Corrections

**Ionospheric Correction**
- Function of user location;
- Up to 100 meters;
- Vertical structure is modelled as a thin shell;
- Ionospheric Correction (IC).

**Clock Correction**
- Same contribution to any user location;
- Not a function of location;
- Fast Correction (FC).

**Orbit Correction**
- Different contribution to different user location;
- Not a function of user location; but a function of line-of-sight direction;
- Long-Term Correction (LTC).

**Tropospheric Correction:** Corrected by a fixed model (Tropospheric Correction; TC).
- Function of user location, especially height of user;
- Up to 20 meters.

FC, LTC and IC are calculated from AL-SBAS transmitted messages.

Ionosphere

Ionosphere

Supposed Orbit

Orbital Error

True Orbit

FC, LTC and IC are calculated from AL-SBAS transmitted messages.
The test transmission of AL-SBAS with a PRN 148 on Alcomsat-1 geostationary satellite was starting in July 20, 2020.

In test period, AL-SBAS transmission is not permanently available for each day and during daytime until 21 May 2021 (day 142).

Availability and number of messages transmitted by AL-SBAS (DOY 2021). The histogram is based on data from DPC (and CNES site).
AL-SBAS Signal-in-Space : Structure & message types

Navigation augmentation information compiling: L1 of AL-SBAS coding is based on RTCA -DO-229; AL-SBAS transmit a navigation message containing 250 bits of information.

<table>
<thead>
<tr>
<th>MT</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PRN mask</td>
</tr>
<tr>
<td>from 2 to 4</td>
<td>Fast correction and UDREI</td>
</tr>
<tr>
<td>7</td>
<td>Degradation Parameters</td>
</tr>
<tr>
<td>9</td>
<td>Message de navigation GEO (X, Y, Z, time, etc.)</td>
</tr>
<tr>
<td>10</td>
<td>Degradation parameters</td>
</tr>
<tr>
<td>18</td>
<td>ionospheric grids points mask</td>
</tr>
<tr>
<td>25</td>
<td>Long term satellite error corrections</td>
</tr>
<tr>
<td>26</td>
<td>Ionospheric delay corrections and it’s GIVE (GIVE)</td>
</tr>
</tbody>
</table>

For PPP applications
The status of each satellite (User Differential Range Error Indicator) → (UDREI : 0-15)

- **Use (UDREI = 0-13)** indicates that the satellite is usable.
- **Not Monitored (UDREI=14)** indicates that the satellite does not appear in the mask or even appearing there are not corrections or UDRE values available for it.
- **Don’t Use (UDREI=15)** indicates that an inconsistency has been found for this satellite (alarm situation) or the estimated fast correction is greater than 256.0 m.
Coverage area of AL-SBAS: Algeria → Ionosphere correction:

\[ \varnothing \text{ Coverage area: } 19^\circ \text{~} 37^\circ \text{N, } 9^\circ \text{W~} 12^\circ \text{E}; \varnothing, \text{ Grid resolution: } 5^\circ \times 5^\circ. \]
MT 26 provide the Ionospheric Delay Corrections (GIVD) and their accuracy in terms of GIVEI (GIVE Indicators) for the IGPs that are configured in the mask.
Grid Ionospheric Vertical Error Indicator (GIVEi)

The status of an IGP (GIVEi : 0-15)

- **Use (GIVEi= 0-13):** There are available IGP delay estimate and GIVEi.

- **Not Monitored (GIVEi =14) :** IGP does not appear in mask or even appearing in mask there is not available delay estimate.

- **Don’t Use (GIVEi = 15) :** An inconsistency is found for this IGP or the GIVE delay is greater than 63.750 m.

![Map showing grid ionospheric vertical error indicator (GIVEi)](image)
Preliminary performance tests (precision) : October 2022

<table>
<thead>
<tr>
<th></th>
<th>GNSS</th>
<th>HPE(95°)</th>
<th>VPE(95°)</th>
<th>3D RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 octobre</td>
<td>GPS</td>
<td>9.81</td>
<td>6.21</td>
<td>5.89</td>
</tr>
<tr>
<td></td>
<td>GPS+EGNOS</td>
<td>1.84</td>
<td>1.43</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>2.00</td>
<td>2.91</td>
<td>2.01</td>
</tr>
<tr>
<td>2 octobre</td>
<td>GPS</td>
<td>8.47</td>
<td>5.68</td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td>GPS+EGNOS</td>
<td>1.83</td>
<td>1.43</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>2.05</td>
<td>2.84</td>
<td>1.95</td>
</tr>
<tr>
<td>3 octobre</td>
<td>GPS</td>
<td>7.49</td>
<td>6.39</td>
<td>5.01</td>
</tr>
<tr>
<td></td>
<td>GPS+EGNOS</td>
<td>1.92</td>
<td>1.52</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>2.22</td>
<td>2.67</td>
<td>1.94</td>
</tr>
<tr>
<td>4 octobre</td>
<td>GPS</td>
<td>11.65</td>
<td>7.70</td>
<td>7.01</td>
</tr>
<tr>
<td></td>
<td>GPS+EGNOS</td>
<td>1.89</td>
<td>1.54</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>2.41</td>
<td>2.82</td>
<td>2.38</td>
</tr>
<tr>
<td>5 octobre</td>
<td>GPS</td>
<td>5.96</td>
<td>6.34</td>
<td>4.64</td>
</tr>
<tr>
<td></td>
<td>GPS+EGNOS</td>
<td>1.69</td>
<td>1.41</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>2.11</td>
<td>2.70</td>
<td>1.89</td>
</tr>
</tbody>
</table>

X, Y and Z coordinates calculated by GPS SPP SF and GPS+AL-SBAS SPP SF (Oran : long = 0.31°W, Lat = 35°N).

3D error

East/North error → mean

East/North error → exact position

UP error → exact position
Integrity is an essential concept for safety that comes from the aviation

Safety Case of SBAS:

→ In order to ensure complete safety, position error must be protected by the associate PL and PL must be < than AL;

→ ESA proposed this chart; Computing for all possible combinations of visible satellites improves integrity.

<table>
<thead>
<tr>
<th>Date</th>
<th>GNSS</th>
<th>Availability APV-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 octobre</td>
<td>GPS+EGNOS</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>98.49 %</td>
</tr>
<tr>
<td>2 octobre</td>
<td>GPS+EGNOS</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>98.19 %</td>
</tr>
<tr>
<td>3 octobre</td>
<td>GPS+EGNOS</td>
<td>100 %</td>
</tr>
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<td></td>
<td>GPS+AL-SBAS</td>
<td>98.17%</td>
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<tr>
<td>4 octobre</td>
<td>GPS+EGNOS</td>
<td>100%</td>
</tr>
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<td>GPS+AL-SBAS</td>
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<td>100 %</td>
</tr>
<tr>
<td></td>
<td>GPS+AL-SBAS</td>
<td>98.05</td>
</tr>
</tbody>
</table>

HPE : Horizontal Position Error, HPL : Horizontal Protection Level, HAL : Horizontal Alarm Limit
Perspective: use Geodetic network (RGSH’2020) to evaluate AL-SBAS

- **22** RGS’2020 Benchmarks (primary network) covering the Algerian territory (2.4 M km²).
- **16** IGS stations.
- **Baselines**: from **300** km to **1450** km.
- **194** Benchmarks for the secondary network: GPS + GLONASS observations.
- **02** continuous GPS measurement sessions (3 and 4 days): in February and March **2020** in static mode.
- **05** points among the 22 points are common to both sessions → Guarantee better network consistency.
- Software processing (**Bernese**, TBC, TEQC, etc.)

**IGS Quality Indicators:**

1. RMS (Root Mean Square) values of individual solutions,
2. Percentage of resolved ambiguities (> 75%),
3. Difference between fixed and float solutions,
4. Repeatability values,
5. Verification of fiducial stations.
IGS Quality Indicators of RGSH’2020 obtained results:

• The RGSH2020 is determined with millimeter accuracy (σ<1 cm): **Accuracy of horizontal coordinates**: Submillimeter, **Heights accuracy ≤ 2 mm**.

• Percentage (%) of fixed ambiguities **is superior than 76.9**.

• The RGSH2020 is linked to the **IGS14 (≈ITRF14) reference system** (consistent with the IGS14 at the time of observation: on February 24, 2020).

• Verification of fiducial stations (7 IGS stations): **rms (N,E,U)** of accepted stations **6 to 8 mm**

The setting up and the results of the **SONATRACH GEODETIC NETWORK (RGSH’2020)** were presented in the previous **ICG Workshop on the Applications of Global Navigation Satellite Systems 25 - 29 October 2021, ULAANBAATAR 2021.**
Perspective: Use of Geodetic network (RGSH2020) to evaluate AL-SBAS

The protocol of test will serve as an external comparison and validation at the borders of Algeria (worst cases).

The first experimental test of AL-SBAS was conducted on site located at 35° of latitude and based on initial analysis of real data during one-week observation in October 2022.
Conclusion

- The current **performance** of Algerian augmentation system based on ALCOMSAT-1 in terms of accuracy, availability and integrity shows a **very promising** results by considering the number of currently available reference stations.

- The encouraging results open the possibility of a better application of the Algerian SBAS corrections. It is recommended to test the availability and the effectiveness of AL-SBAS corrections by using **real time positioning**.

- As a futur work, the final tests will be conducted, considering the **worst cases** of the coverage, at the borders of the country, and the RGSH, to evaluation the real precision of the system at the **boundary** of the actual coverage.

- The system as defined (as the problem of accuracy and integrity is solved), cannot yet be **certified** according to ICAO standard for civil aviation if **redundancy** is not ensured in all phases of project (AL-CORS network, which is also highly redundant; Data transmission (GSM + Internet or VSAT); but also transmission to users (telecommunications satellites).

- Encourage the **cooperation between the African** air navigation services providers to accelerate the SBAS services deployment and provision to meet requirements of the airspace users already interested → Extend the coverage of AL-SBAS system by **adding ALCORS stations in neighbouring** countries (Mali, Niger,....Nigeria) in order to improve the performance of the system.