

IALA GUIDELINE

G1129

THE RETRANSMISSION OF SBAS CORRECTIONS USING MF-RADIOBEACON AND AIS

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1. INTRODUCTION

It is recognised that while Global Navigation Satellite Systems (GNSS) have become the primary means of obtaining Position, Navigation and Timing (PNT) information at sea, augmentation is required to ensure the necessary level of integrity is achieved and accuracies improved, over the use of GNSS alone.

While ground based augmentation systems (GBAS), such as marine radio beacon DGNSS have been in use for some time, recent developments have enabled Satellite Based Augmentation Systems (SBAS) to be considered for maritime use.

There are many SBAS in operation around the world, largely serving the Northern Hemisphere. While originally developed for aviation users, their use in the maritime sector is increasing. This document aims to set out where marine Aids-to-Navigation service providers could use SBAS within their service provision.

2. SCOPE

This document sets out guidance for marine Aids to Navigation (AtoN) service providers wishing to understand where SBAS information could be used to support the mariner and then how to employ such data.

While it is expected the mariners will use SBAS direct Signal in Space (SiS), the main purpose of the document is to describe the SBAS use within augmentation services via marine radio beacon and AIS transmissions. The document aims to consider common SBAS functionality, rather than focus on any specific SBAS system, but does refer to specific SBAS services where required.

The document provides an overview of SBAS structure, use and general coverage areas. For the sake of completeness, the direct use of SBAS from SiS on-board is introduced in section 3.1 and complementary information is included in different annexes.

Recognising that the generation of differential corrections can be split from the means of transmission, a number of different example architectures are provided in Section 4. These are meant as examples, recognising that the infrastructure deployed and operational architecture will vary between service providers.

Finally, operational aspects are addressed in section 6.

3. SBAS USE IN MARITIME

There are a number SBAS in operation, Annex A provides further information of SBAS basic architecture, and Annex C provides information about current SBAS systems.

Satellite-Based Augmentation Systems are designed to augment the GNSS by providing correction data and integrity information for improving positioning, navigation and timing.

GNSS measurements are made at accurately located reference stations, deployed across a wide area. The data from these is then provided to a central processing element, which calculates differential corrections and integrity information for the constellation, or constellations monitored.

This information is then broadcast over the service area using satellites. There are several SBAS services in operation around the world, currently providing regional coverage areas within the northern hemisphere, all of which provide interoperable signals from the various satellites. See annex A for more detailed information.

There are different approaches on how SBAS data could be used in the maritime sector.

- SBAS Data used from Satellites (Signal in Space);

- SBAS Data used via Maritime Service providers' AtoN.

In the second case, SBAS data can be provided to the mariner over an existing marine radio service currently used for a recognized AtoN, such as marine radio beacon MF (283.5-325 kHz) or VHF frequencies used for AIS.

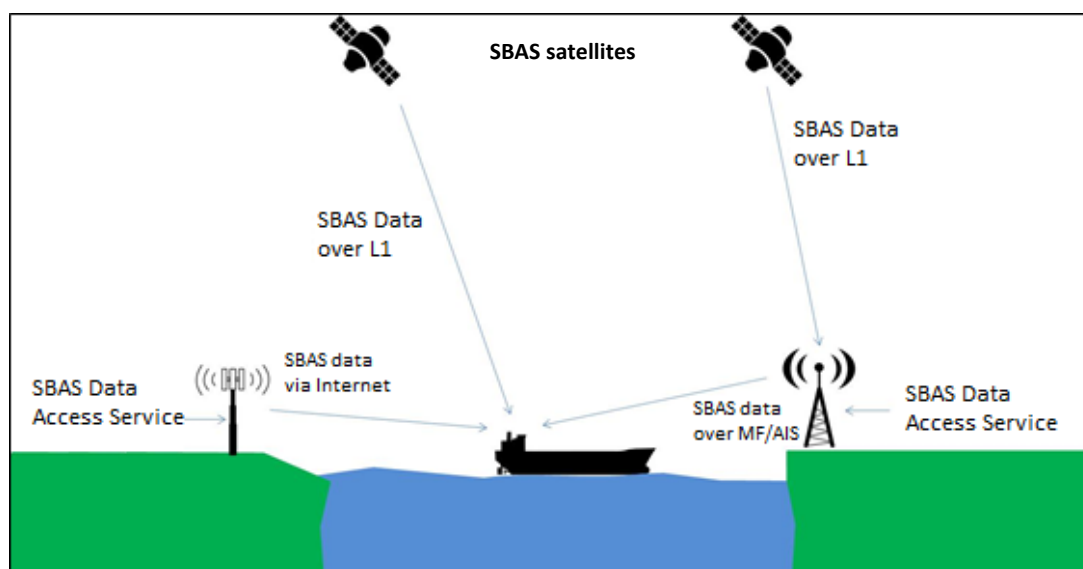


Figure 1 *Generic view of the different SBAS transmission/reception options in the maritime sector*

3.1. SBAS SIGNAL IN SPACE (SIS)

The most straightforward solution for the introduction of SBAS in the maritime domain is to use directly the augmentation corrections received from the satellites.

SBAS SiS is currently available and used by non SOLAS vessels to improve the GNSS accuracy. As explained below, at the time of publication there is no receiver equipment performance/test standard published for SBAS in support of SOLAS applications.

The main advantage of this option is the availability of an augmentation solution even in areas where DGNSS services are not available, not deployed or out of the range of maritime users. In addition, this solution typically has no cost for maritime authorities nor for the final users, as the SBAS service is provided free of any direct user charge.

The accuracy performance is similar in average to that indicated in [4] for DGNSS (<5m, 95%) with homogenous performances in the SBAS service area in comparison with DGNSS where the accuracy performance is higher in the vicinity of the beacon and degrades with the distance.

The administrations seeking to use or recognize SBAS services for maritime applications should consult the SBAS service provider in the area (see ANNEX C) regarding the service performances for maritime/merchant shipping use. The current SBAS systems typically meet the IMO Resolution A.1046 (27) [12] operational requirements¹ for navigation in coastal waters, harbour approach and harbour entrances. The table below summarizes those requirements.

¹ SBAS service based on IMO Res. A.1046 (27): EGNOS Maritime performance, ION GNSS+ 2017

EGNOS Multimodal Performances, Coordinates June 2017

<http://mycoordinates.org/egnos-multimodal-performance>

http://www.dke-aerospace.com/index.php?option=com_content&view=article&id=190:maritime-applications&catid=27:system-engineering&Itemid=28

Maritime operational requirements on IMO A.1046 (27)						
	Horizontal Accuracy 95%	Signal availability	Service continuity (over 15min)	Position update rate	Integrity warnings ¹	System coverage
Ocean waters	100m	99.8%	-	2s	MSI as soon as practicable	Adequate ²
Harbour entrances, harbour approaches and coastal waters	10m	99.8%	99.97%	2s	10s	Adequate ²
¹ Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities.						
² Taking into account the radio frequency environment, the coverage of the system should be adequate to provide position-fixing throughout this phase of navigation.						

Table 1 Maritime Operational Requirements. IMO A. 1046

However, although SBAS is commonly supported by most of GNSS receivers, there is no maritime standard for the SBAS systems in the maritime segment. As a result, implementation of SBAS currently performed by maritime receiver manufacturers is not fully standardized for maritime use. In this regard IMO MSC adopted in 2015 the Multisystem Receiver Performance Standards including SBAS. This work was completed with the definition of Guidelines for shipborne PNT (data processing) [31] unit adopted by IMO MSC in 2017, and will be followed by the development of the appropriate IEC Test Specification, using the work being carried out in RTCM:

There are initiatives to define in the medium term (2019-2020) a specific SBAS service, based on the SiS, fully compliant with the operational requirements of the IMO Resolution 1046 [12] with the intention to further evolve towards a service compliant with the IMO Resolution A.915. These include:

- 1 SBAS IMO WWRNS Recognition
- 2 IMO MSC98 stated there is no need to follow a process of recognition for SBAS once the Core constellations are recognised, which is the case of GPS, GLONASS, BEIDOU and Galileo.
- 3 SBAS Service Provision aspects
- 4 EGNOS Requirements under consolidation under the European Maritime Radio navigation² Forum (EMRF) –Service Provision Working Group.
- 5 Standardization – SBAS RX Guidelines
- 6 RTCM SC-104 has established a SBAS WG to develop a guideline for manufacturers to implement SBAS in shipborne receivers compliant with the IMO Res. 1046
- 7 Standardization – Multisystem Rx including SBAS.
- 8 IMO MSC.401 (95), adopted in 2015, established the performance standards for multi-system, including augmentation, shipborne radio navigation receivers MSC 401 is expected to come into force in 2018. The IEC performance requirements (IEC TC 80) and tests specifications are the next step with fully approved receiver hardware expected to be available 2019/2020.

Maritime administrations or AtoN service providers should consider the regulatory requirements as part of the process for implementing SBAS in AtoN augmentation services.

² <http://emrf.eu/>

The main benefits for the on-board direct use of SBAS SiS are:

- Improved position accuracy and integrity information (receiver implementation under a standardization process. See above) with respect to GNSS when no other DGNSS service is available
- SBAS Systems are interoperable
- Homogeneous performances over the SBAS service area
- Free of any direct user charge
- Large coverage including areas not served by other DGNSS beacons

3.2. SBAS DATA USED VIA MARITIME SERVICE PROVIDERS' ATON

The potential use of SBAS as a source for the generation of DGNSS corrections, including the required integrity checks, is described in section 5. The principle behind this solution is to convert the SBAS augmentation message (RTCA format) into RTCM SC-104 corrections referenced to the locations of interest for maritime users (e.g. beacon locations). For example, transmission to end users can be done through marine radio beacons or AIS base stations (via AIS #17 message), hence ensuring compatibility with the already deployed equipment at user level. Three subcategories are presented in the document:

- Transmission of SBAS derived corrections over DGNSS stations (marine radio beacons)
- Transmission of SBAS derived corrections over AIS stations
- Transmission of SBAS corrections over future VDE data channels (further information in section 4.3)
- Regarding the access to the SBAS data, two different options are also considered:
- **SiS:** The source for the generation of the DGNSS corrections (RTCM 2.x) to be broadcast by the marine radio beacons or AIS is the SBAS Signal in Space.
- **Internet:** Some SBAS providers can deliver corrections by internet e.g. EGNOS EDAS (Data Access Service). Therefore, this option has been also considered when analysing the SBAS source for the generation of the DGNSS corrections (RTCM 2.x) to be broadcast.

4. SBAS DATA USED VIA MARITIME SERVICE PROVIDERS' ATON

The analysis and description of these solutions is based on functional and technical aspects. Apart from this, the economic aspects are also addressed in the generic cost analysis included within the IALA ENAV 20.13.16 [34].

ANNEX E includes an example on how SBAS messages in RTCA format could be mapped into RTCM 2.x format.

4.1. SBAS OVER DGNSS MESSAGES (IALA BEACON)

IALA DGNSS concept employs the principle that the main sources of error in satellite navigation (i.e. satellite clock errors, satellite ephemeris errors, tropospheric and ionospheric delay estimation errors) are highly correlated for two users located relatively close to each other.

Differential GNSS corrections are computed by placing a reference station with a GNSS receiver at a known location, determining corrections to the satellite ranging signals, and broadcasting these corrections to users. Then, since the satellite locations and reference antenna location are known, the ranges can be determined precisely. By comparing these ranges to those obtained from the satellite pseudorange measurements, the pseudorange errors can be accurately estimated and corrections determined. These corrections can then be broadcast to nearby users, who use them to improve their position solutions,

removing the bias errors common to the reference station and user receivers. User receiver noise, inter-channel biases, user local effects and potential errors in the antenna surveyed position could limit the corrections accuracy.

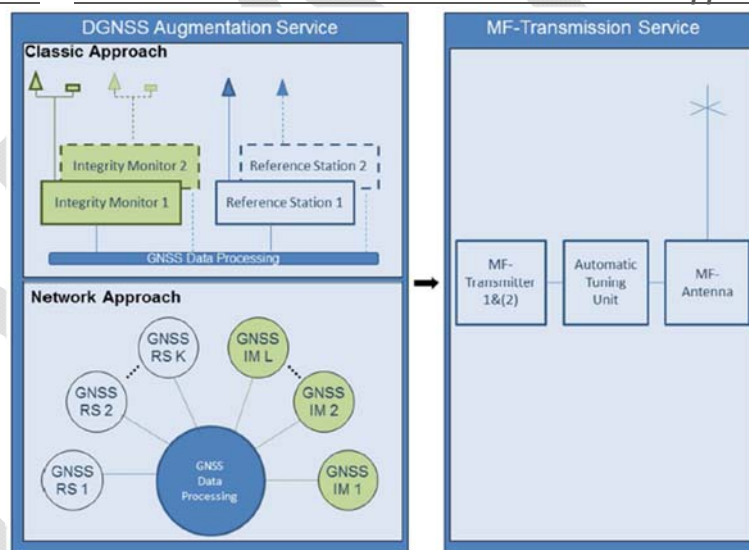
The SBAS systems provide corrections to the same errors (i.e. satellite clock and ephemeris errors along with ionospheric delay estimation errors), with one exception: the troposphere. For this error source, SBAS systems do not provide corrections; the conversion process (see annex E) will apply a model to reduce the error in the position due to this effect.

Considering this, the SBAS messages can be used for the generation of local area corrections in RTCM format, which can be part of a solution fully compatible with the user equipment already deployed. This could provide some room for the rationalization of the infrastructure. Additionally, local effects potentially affecting the classical approach (e.g. multipath or antenna position not well surveyed) would not impact the quality of the SBAS-based corrections.

On the other hand, as described in the IALA Guideline 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz [4], marine beacon infrastructure can be considered to fall into two different architectures, with either equipment all sited at the broadcast locations (classic approach), or some of the infrastructure is centralized with only the transmitting equipment at the broadcast site (network approach).

While this generalization can be made, there will be subtle differences within each installation, depending on the degree of risk associated with communication failure, hardware failure and the cost/time associated with attending the site for maintenance.

Figure 2 DGNSS Service Architecture: Classic and Network Approach [4]



The information presented hereafter explains the possible functional ways to integrate SBAS data into these architectures. The starting point is the selection of a baseline architecture used as a reference for the analysis.

The benefit provided by SBAS on the analysed architectures and of their potential drawbacks/limitations, is presented by comparison with respect to classical approach architecture.

4.1.1. BASELINE ARCHITECTURE

This baseline architecture has been defined as a DGNSS service based on the classic approach (IALA Guideline 1112 [4]) including the Reference Station (RS) and the Integrity Monitoring (IM) modules.

It is also noted that this architecture is commonly doubled (two parallel processing streams in figure 3) in order to meet the availability requirements defined by IMO Resolution A.1046 [12].

Figure 3 *Baseline redundant IALA Architecture*

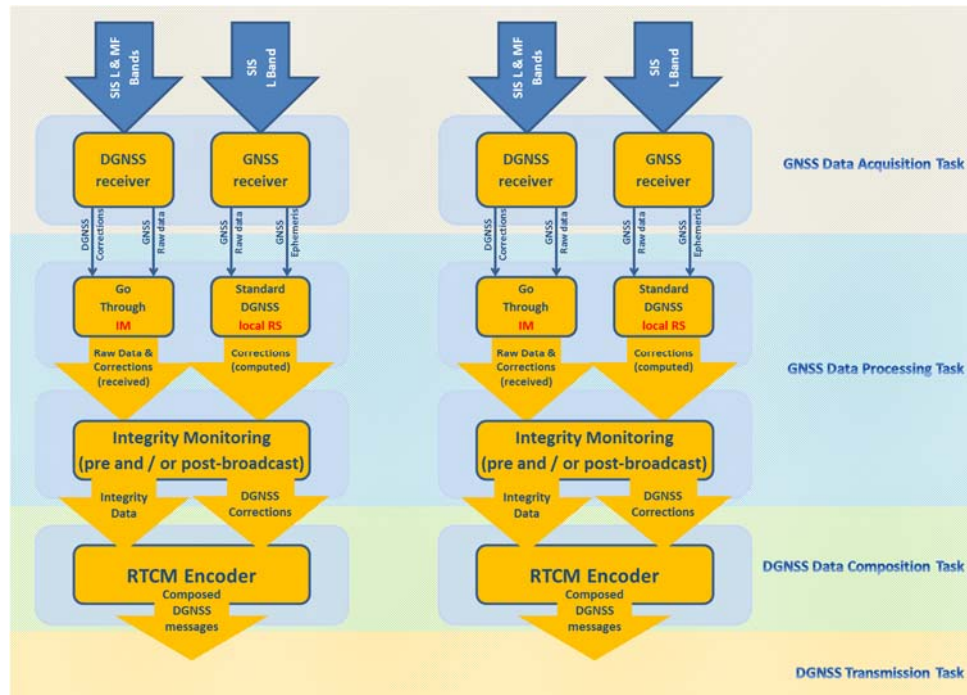


Figure 3 includes a functional representation of the baseline architecture of the Reference Station component that computes the pseudorange corrections based on the GNSS raw data (observations and ephemeris) collected by a GNSS receiver and the surveyed position of the station. These corrections are then encoded in RTCM format and MSK modulated, to be transmitted to the users in the LF/MF band (285 - 325 kHz).

The integrity of the corrections transmitted to the users, is checked by the Integrity Monitor module, which processes the GNSS raw data and the corrections generated by the RS and collected by a DGNSS receiver.

This architecture allows both Pre-Broadcast and Post-Broadcast integrity Monitoring concepts. The Post-Broadcast Monitoring concept not only monitors the integrity of the data but also the availability of the radio link and the quality of the signal transmitted. This is one of the major differences with respect to the Pre-Broadcast concept, which includes the integrity monitoring functionality, but does not check the availability of the MF radio link. On the other hand, the Pre-Broadcast approach ensures that all the relevant integrity checks have been performed before DGNSS data is transmitted. Service providers can use pre and post broadcast integrity monitoring at the same time.

4.1.2. SBAS OVER DGNSS TRADE-OFF ANALYSIS

The three architectures presented in the following sections have been selected based on a trade-off analysis that compares each of the solutions identified [15] for the provision of SBAS-based DGNSS corrections via IALA beacons with respect to the baseline architecture described in previous section.

This trade-off analysis takes into account a set of key features (described in Table 2) derived from the baseline architecture and considers the following colour code:

- Green colour: Feature improved w.r.t. the baseline.
- White colour: Same as the baseline (no improvement/degradation)
- Red colour: Feature degraded w.r.t. the baseline.

Among the identified criteria, the following ones are considered mandatory or highly recommended for an SBAS-based architecture:

- Mandatory (highlighted in bold in the table): “Legacy on-board receivers compatibility” (LEG) and “Integrity Monitoring” (IM) features.
- IALA recommendations (highlighted with an asterisk (*) in the tables): “MF link monitoring” and “Corrections generation separated from the transmission technology” features [4].

Taking into account this trade-off assessment, three architectures have been selected as the more convenient solutions for the provision of SBAS-based DGNSS corrections via IALA beacons:

- Hybrid Decentralised Architecture: classical DGNSS + SBAS (SiS or internet) based decentralized
- Hybrid Centralised Architecture: classical DGNSS + SBAS (SiS or internet) based centralized
- Redundant Fully SBAS Based Solution

In any case, it should be noted that the assessment of the most convenient architecture for each particular scenario shall be based on a case by case analysis. This analysis shall take into account the topology of the existing IALA DGNSS infrastructure (if any) - network or classic approach, the availability of communication lines connecting the different elements comprising the current architecture or the type of GNSS receivers available (SBAS enabled or not), among other technical aspects and also any relevant operational/service requirement provided by the target maritime authority.

The three architectures presented in the following table (right columns) have been identified as the most beneficial ones among the many different possibilities considered in trade-off assessment [15]. These architectures will be depicted in the following sections.

Service providers should note that any other architectures assessed on the trade-off analysis should not be excluded because the assessment may vary depending on their specific implementation scenarios.

Key feature used for the assessment	Levels of implementation			Proposed Architectures – Trade Off Assessment				
	Improvement w.r.t. baseline	Baseline	Degraded w.r.t baseline	Hybrid Decentralised		Hybrid Centralised		Redundant Fully SBAS
Infrastructure at site (INF)	Reduced infrastructure	Similar infrastructure. 2 RS + 2 IM (with MF Rx)	Additional infrastructure					
Legacy receivers compatibility (LEG)	N/A	The information broadcast (differential corrections) is compatible with the legacy receivers (RTCM format)	The information broadcast (differential corrections) is NOT compatible with the legacy receivers					
Integrity monitoring (IM)	The architecture includes additional Integrity check	The architecture includes integrity monitoring	The architecture does not include integrity monitoring					
Local effects impact corrections (LOC)	Local errors do not affect the differential corrections	Local errors, such as multipath, receiver noise or masking effects may affect the reference station	N/A					
Type of Communication lines (COM)	No communication lines	Standard communication lines (high-availability communication lines not needed) to connect the RS & IM to the remote CS.	High availability communication lines needed to ensure the IMO availability requirement					
MF link monitoring (MF *)	N/A	The architecture includes the capability of monitoring the MF radio link	The architecture does not include the capability of monitoring the MF radio link					
Redundancy (RED)	Increased redundancy with respect to the baseline architecture	Same redundancy as the baseline architecture (2 RS & 2IM)	Decreased redundancy with respect to the baseline architecture					
Jamming and Spoofing Resiliency (JSR)	In case of jamming attack in the vicinity of the reference station, the DGNSS service will not be affected	In case of jamming attack in the vicinity of the reference station, the DGNSS service will be affected	N/A					
Corrections generation separated from the transmission technology (SEP *)	Yes	No	N/A					

Table 2 *Key features description and Trade-Off assessment*

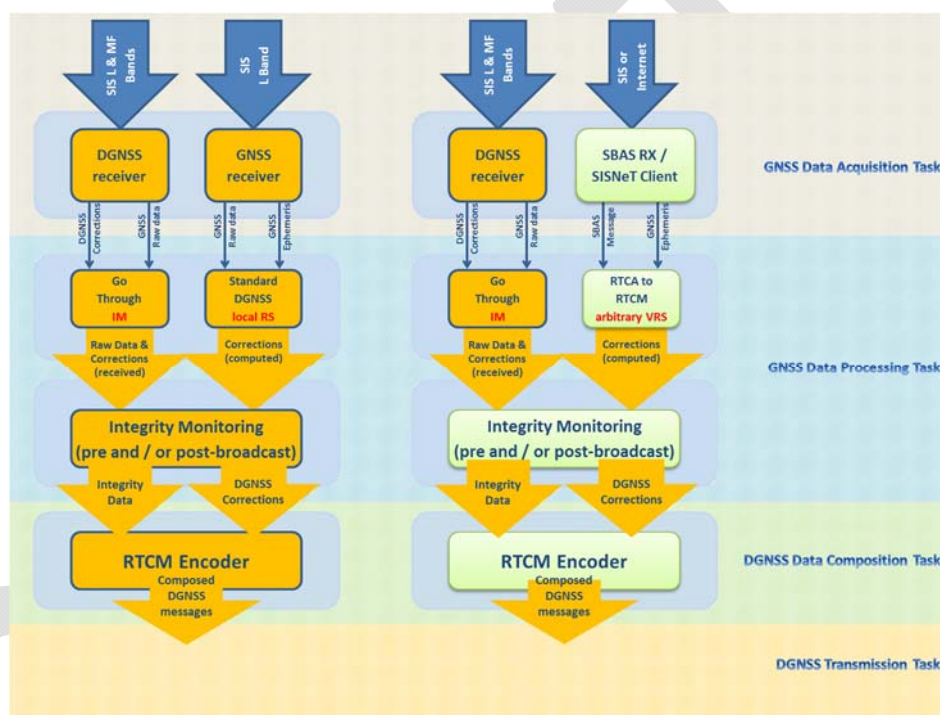
It has to be noted that there are several features for which the assessment depends on the data used in the reference station or the integrity monitoring. For instance, for the “Hybrid Centralised” solution, the assessment of the “Local effects impact corrections” depends on which corrections are finally transmitted to the users: the corrections generated by the decentralised DGNSS solution or by the centralised SBAS based architecture. In that case, the corresponding cell has been split to account for the two possible options (see Table 2 above).

The particular details of these three architectures are described in the sections below

4.1.3. HYBRID DECENTRALISED ARCHITECTURE: CLASSICAL DGNSS + SBAS (SiS OR INTERNET) BASED

This is a redundant decentralised solution, combining the classical DGNSS configuration (left side in Figure 4) and the SBAS based architecture (right side in Figure 4), which counts on two RS and two IM locally onsite.

Figure 4 Hybrid Decentralised Architecture: classical DGNSS + SBAS (SiS or SISNeT³) Based



The two IM parts (including the IM SW module and the DGNSS receiver) are identical in terms of functionality⁴ (all inputs/outputs are the same w.r.t the classical architecture):

- Corrections will be in RTCM format in any case, accessed after broadcast by the transmitter (post-broadcast integrity monitoring) or from the corresponding RSIM message delivered by the RS (pre-broadcast).
- The feedback to be sent to the RS is not modified. If the post-broadcast integrity monitoring concept is used, the IM will need to have a DGNSS receiver to access the GNSS measurements from the satellites.

In the SBAS-based chain the GNSS receiver and the standard reference station are replaced by a SBAS enabled receiver and a RTCA to RTCM converter. All the components highlighted in the following figure

³ On what regards to the SBAS use through internet this is an example because this is a specific EGNOS EDAS implementation [29]

⁴ In order to ensure interoperability with commercial the Integrity Monitoring module and the Control Station, the SBAS module should be compliant with RSIM standard

(SBAS receiver, RTCA to RTCM converter, Integrity Monitoring and RTCM encoder) could be integrated in a single SW module. This module would be responsible for:

- Getting the SBAS corrections and GNSS ephemeris from the SBAS SiS.
- Converting the SBAS messages into DGNSS corrections in RTCM format.
- Checking the integrity of these corrections (pre and/or post broadcast) based on the information provided by the DGNSS receiver.
- Encoding the differential corrections together with the integrity data in RTCM format.

In order to reduce the infrastructure needed at each beacon site (maintaining redundant Integrity Monitoring architecture), the raw data collected by the GNSS receiver and/or the DGNSS receiver of the classical architecture (left chain in the figure) could be used by the integrity monitoring module of the SBAS based solution (right chain).

A variant for this architecture is to replace the SBAS enabled receiver by an EGNOS **EDAS SISNeT client**⁵. In that case, internet connectivity will be needed in the reference station. It should be noted that, when connecting to EDAS SISNeT service, it is needed to choose between the two operational EGNOS GEO⁶ satellites. Hence, in order to not penalize the availability of the GPS corrections with respect to the option based on the access to the SBAS messages through the SIS (SBAS compatible receiver is capable of tracking multiple GEOs), two EDAS SISNeT clients shall be used, each of them connected continuously to one EGNOS GEO satellite. Then, the SW to convert from RTCA to RTCM should include a GEO switch function.

Regarding the trade-off assessment presented in Table 2, the analysis of the key features improved by the SBAS-based chain with respect to the baseline architecture is hereafter detailed:

- **Local effects impact:** As detailed in section 5, the fact that the GNSS raw observations are not used for the corrections generation implies that any local effect such as multipath, receiver clock jump/offset or masking effects would not affect the quality of the SBAS-based corrections.
- **Jamming and Spoofing Resilience:** In case of getting the SBAS message and GPS ephemerids from the EDAS SISNeT service, an eventual jamming attack near the RS would have no impact on the SBAS-based corrections generation.

However, it is noted that depending on the location of the GNSS receivers used for the integrity check, the IM module may be also affected and therefore the SBAS-based solution as well.

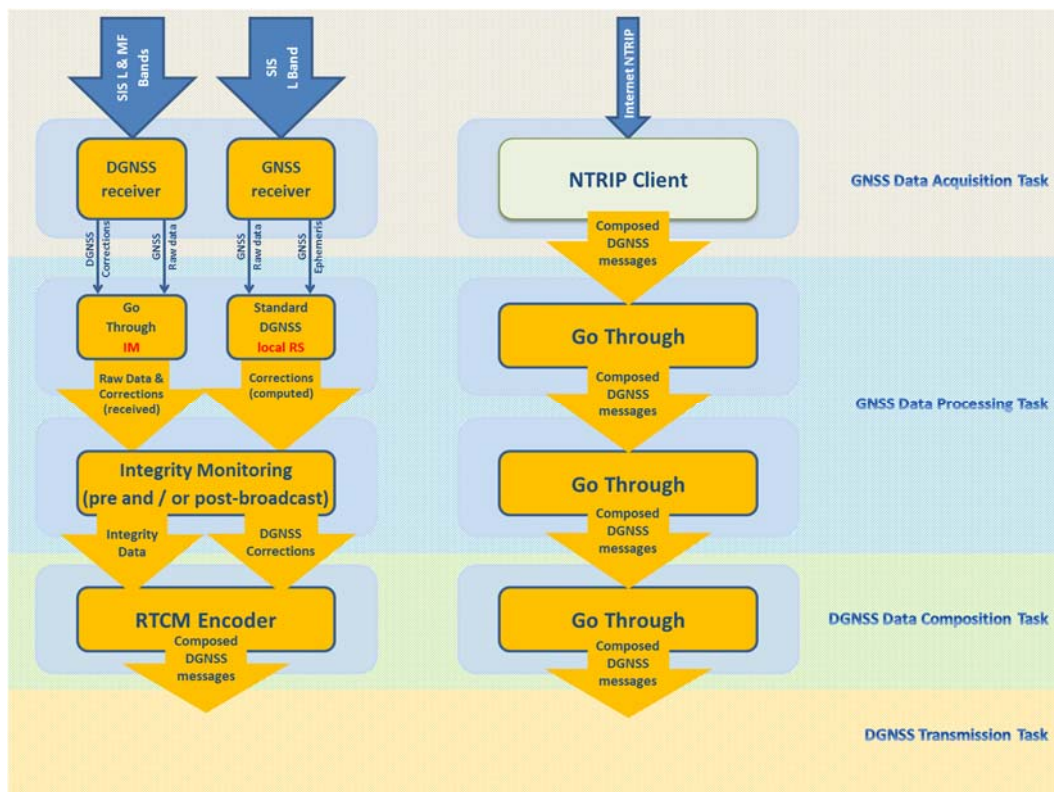
4.1.4. HYBRID CENTRALISED ARCHITECTURE: CLASSICAL DGNSS + SBAS (SiS OR INTERNET) BASED VRS

This solution (see Figure 5) combines a classical DGNSS station deployed at each beacon site with a centralised SBAS based VRS solution.

⁵ This is a specific EGNOS EDAS solution when using internet

⁶ In the EGNOS case the satellites providing the corrections are Geostationary satellites

Figure 5 Hybrid Centralised Architecture: classical DGNSS + SBAS Based VRS⁷



For the SBAS-based VRS solution (right chain), both the RS and the IM stations are centralised in the “Central Facility”, and therefore, the only infrastructure needed at each beacon site is the communication lines, client to get the corrections (e.g. NTRIP) and the transmission equipment. On the other hand, it is noted that the network approach results in high requirements concerning the availability and quality of the communication links (IALA Guideline 1112).

The SBAS-based centralised solution is based on the pre-broadcast monitoring approach, using the raw data collected by a network of GNSS receivers to check the integrity of the generated corrections and a network of MF receivers, to monitor the radio link availability and the quality of the signal transmitted. For a post-broadcast check, far-field integrity remote monitoring stations could be used.

The DGNSS and GNSS receivers in the classical DGNSS architecture (left chain in figure above) could be also used to monitor the signal and corrections transmitted by the SBAS based solution (right chain in the figure below).

Apart from the reduction of HW/SW components of the SBAS based centralised solution at each beacon site, another advantage of this solution is that it is resilient in front of jamming attacks in the vicinity of the reference station. In that situation, the classical reference station will not be able to collect GNSS raw data and therefore not able to generate differential corrections. However, the SBAS based VRS solution will not be affected by this event.

Summarising, the assessment of the key features highlighted in green in Table 2 (improvement with respect to the baseline architecture) is detailed hereafter:

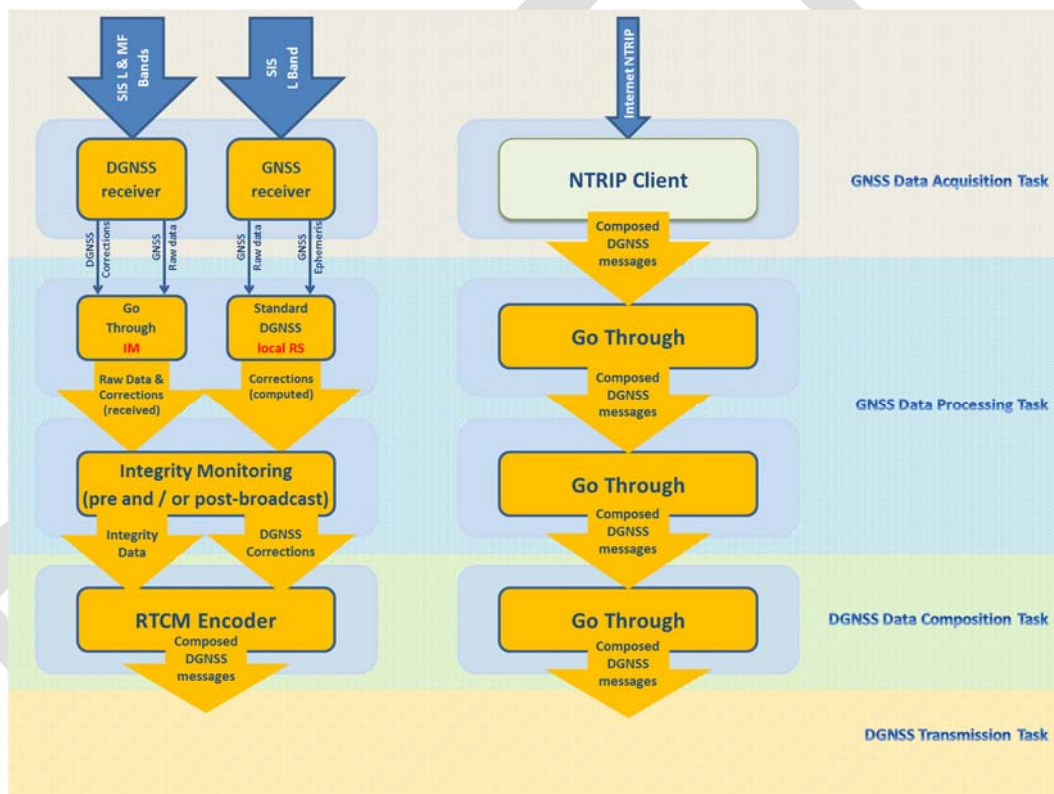
- **Infrastructure reduction.** As mentioned before, no RS neither IM is needed at each beacon for the the SBAS-based VRS solution (right chain). Being possible therefore to reduce the HW and SW

⁷ “Go Through” module: means that no change on the data is done on this layer at the broadcast site. For instance, in the centralised solution, corrections (including integrity) are received at the broadcast site, being only necessary to transmit this data via radio. Hence, no action is done in the “GNSS data processing and composition” tasks.

components needed at each station, with the corresponding benefits in terms of deployment cost, power consumption, maintenance cost or operational procedures

- **Local effects & Multipath.** Refer to the comments provided in previous section
- **Jamming and Spoofing Resilience.** Considering that the SBAS-based corrections are generated and integrity checked in a central facility (not at each station), an eventual jamming or spoofing attack in the vicinity of the beacon site would have no impact on the service (the classical approach chain –left side – would be affected but there will be no impact on the SBAS-based centralised solution – right chain).
- **Corrections generation separated from the transmission technology.** Apart from the local effects and jamming resilience benefits detailed above, the fact that the corrections are separated from the transmission means also has other benefits such as the flexibility of providing the computed corrections via different means. For instance, the SBAS-based centralised solution can be used to feed not only IALA beacons but also AIS stations as described in section 5.2.

Figure 6 Hybrid Centralised Architecture: classical DGNSS + SBAS Based VRS⁸



The Central Facility computes the Pseudorange Corrections for all the satellites above the elevation mask on the place of the VRS. PRCs and ancillary information (e.g. antenna location) are encoded into RTCM 10402.3 [6] and transmitted to each beacon transmitter site. This Central facility is composed of the following modules:

- **SBAS enabled Receiver:** Providing access to the SBAS satellites correction messages transmitted including GNSS navigation data required for the RTCA to RTCM conversion and GNSS ephemeris.

⁸ "Go Through" module: means that no change on the data is done on this layer at the broadcast site. For instance, in the centralised solution, corrections (including integrity) are received at the broadcast site, being only necessary to transmit this data via radio. Hence, no action is done in the "GNSS data processing and composition" tasks.

The main functionality of this module is to implement a real-time interface for the reception of this data on a second by second basis, and to provide the SBAS message in RTCA format and the ephemeris to be injected to the PRC estimator module.

It is recommended to install at least two receivers at two different locations to mitigate the impact of any interference or jamming attack near the receiver.

In case of the European EGNOS service, it is also possible to use a **SISNeT client** to access the SBAS augmentation message (this solution would be resilience to local interferences). The SISNeT protocol, not only allows the users to receive on real-time the EGNOS message through internet but also the GPS navigation data, required for the RTCA to RTCM conversion. Two SISNeT clients shall be used, each of them connected continuously to one EGNOS GEO satellite. Then, the SW to convert from RTCA to RTCM should include a GEO switch function.

- **PRC Estimator: The primary function of the PRC estimator is to compute the Pseudorange Corrections** for satellites above the elevation mask angle for each Virtual Reference Station (VRS). In order to compute these corrections, the PRC Estimator uses as input the following information:
 - Beacons location: This could be obtained from a configuration file, containing the antenna position (WGS-84 datum) for each VRS location;
 - GNSS Navigation message: GNSS ephemeris are provided by the SBAS receiver or GPS in case of EGNOS SISNeT client. They are used to perform the RTCA to RTCM conversion;
 - SBAS corrections in RTCA format.

Then the SBAS-based DGNSS corrections (including SBAS integrity alerts) are then transmitted to the Integrity Checker module.

- **The Integrity Checker:** implements the classical **pre-broadcast integrity** concept by applying the SBAS-based DGNSS corrections to the GNSS raw data collected by the Integrity Monitoring network. This network could be a dedicated/proprietary one (set of receivers specifically deployed within the coverage area) or a GNSS networks provided by an external entity (public or private), independent from the generation of corrections

Therefore, the Central Facility shall implement a module responsible for retrieving the GNSS data from the network of receivers located along the area of service. The main tasks of this module are:

- To manage the communication with the different receivers;
- To select an available GNSS receiver within the coverage range of each beacon transmitter. In case of failure of one of these receivers, this module shall be able to switch to another receiver within the coverage range;
- To process the information collected (GNSS measurements) from the receivers and distribute this data to the Integrity Checker module.

The Integrity Checker, using as input the SBAS-based DGNSS corrections, the raw data collected by the Monitoring Network and known information (e.g. Surveyed receiver position), checks the integrity of the corrections both at the Position and the Pseudorange domains.

- **RTCM Encoder:** finally, the SBAS-based DGNSS corrections computed by the PRC estimator along with the integrity flags set by the Integrity Checker are provided to the 'RTCM encoder' module, responsible for encoding all this information in RTCM 10402.3 format.

4.1.5. REDUNDANT FULLY SBAS BASED SOLUTION

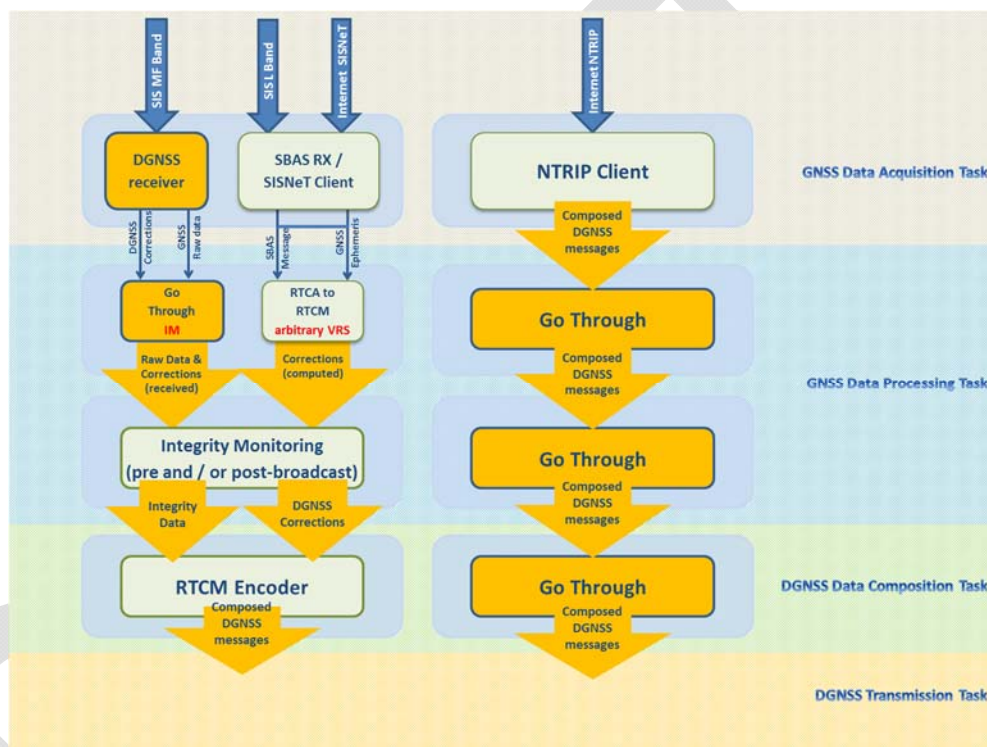
This is a fully SBAS based solution, combining the decentralised (left chain) and centralised (right chain) approaches.

The centralised solution corresponds to the architecture presented in the previous section (right chain), where the RS and the IM stations are centralised in the “Central Facility”. For the decentralised solution (left chain), it is noted that the SBAS corrections can be obtained from an SBAS enabled receiver or from the EDAS SISNeT service.

The raw data collected by the GNSS receiver and/or the DGNSS receiver of the decentralised architecture (left chain in the figure) could be used by the integrity monitoring module of the SBAS based centralised solution (right chain).

Regarding the assessment of the key features improved with respect to the baseline architecture (highlighted in green in Table 2), the same comments provided for the Hybrid Centralised Architecture (see section 4) are also applicable to this architecture, with the only difference that local effects would neither affect the decentralised chain (left side in Figure 7)

Figure 7 Fully SBAS Based Solution



4.2. SBAS OVER AUTOMATIC IDENTIFICATION SYSTEM (AIS)

The provision of DGNSS corrections is an optional functionality of the AIS system transmitted through the AIS Message 17 [33]. The estimated load for the transmission of SBAS corrections is less than 1% of VDL capacity [2][32].

The present section provides a high level description of the architectures that could be used to generate DGNSS corrections from the SBAS message, obtained from SIS and/or from Internet (EGNOS EDAS), and broadcast them over AIS base stations (using AIS VDL AIS Message 17).

Two different solutions are analysed for the generation of differential GNSS corrections to be transmitted by AIS base stations, depending on the existing AIS service architecture:

- SBAS based DGNSS solution over decentralised AIS service (based on the use, locally at the AIS station of the SBAS corrections accessed through the SIS or Internet)
- SBAS based DGNSS solution over centralised AIS service (for the generation of virtual corrections for each AIS base station in a central facility).

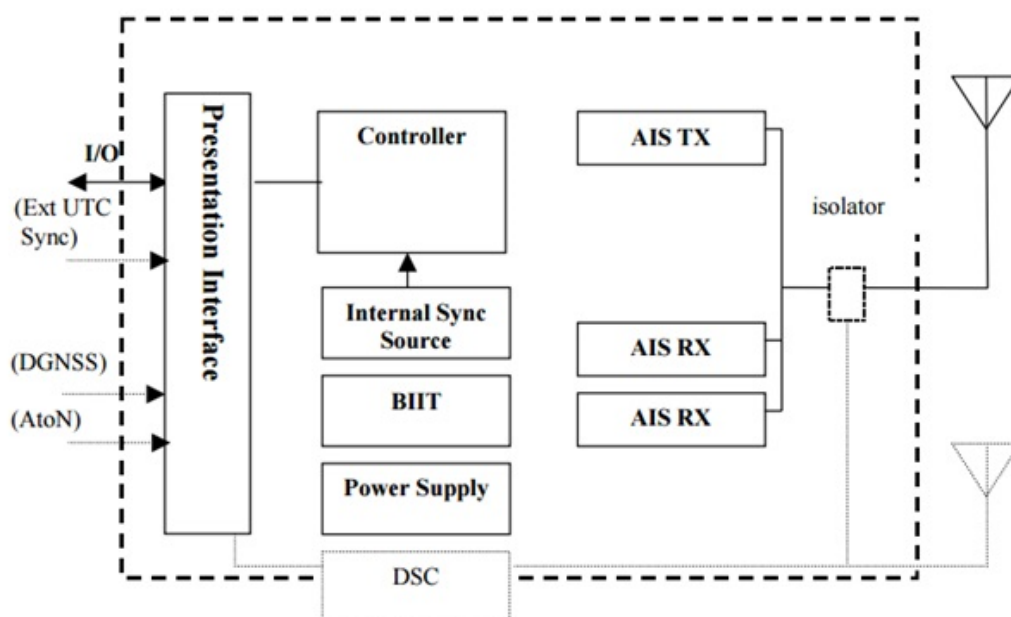
It is to be noted that the integrity monitoring check is recommended for the transmission of DGNSS corrections via AIS [2]. In case the DGNSS corrections are obtained from an IALA Beacon, the integrity of the corrections is already checked by the reference station. However, in case a dedicated station is deployed, local integrity monitoring is required [1].

4.2.1. BASELINE ARCHITECTURE

For a better understanding of the added value of the SBAS based solutions considered and of their potential drawbacks/limitations, a comparison with respect to an arbitrary baseline architecture, where SBAS is not used, was done.

The arbitrary baseline architecture for the provision of DGNSS corrections over AIS has been defined as an AIS service getting the pseudorange corrections in RTCM format (including integrity) from a classical DGNSS reference station. It is also assumed that standard communication lines are available at the AIS base station. This baseline has been selected under the understanding that it is the typical (or one of the most common) set-up used today to provide DGNSS corrections over AIS.

Figure 8 Functional block diagram of an AIS base station[2]



4.2.2. SBAS OVER AIS TRADE-OFF ANALYSIS

The two architectures presented in the following sections have been selected based on a trade-off analysis that compares each of the solutions identified [15] for the provision of SBAS-based DGNSS corrections via AIS-base stations with respect to the baseline architecture described in previous section

This trade-off analysis takes into account a set of key features (described in Table 3) derived from the baseline architecture and considers the following colour code:

- Green colour: Feature improved w.r.t. the baseline.
- White colour: Same as the baseline (no improvement/degradation).
- Red colour: Feature degraded w.r.t. the baseline.

It should be noted that all the architectures analysed [15] provide integrity monitoring. For that reason, the “integrity monitoring” capability has not been included in the trade-off analysis, since there is no difference among the architectures addressed.

Based on the analysis of the key features presented before, among the solutions analysed [15] the most convenient architectures are:

- SBAS based DGNSS solution over centralised AIS service.
- SBAS based DGNSS solution over decentralised AIS service.

It should be noted that the best alternative to be selected for each case would depend on the type of service provided and on the operational scenario under analysis (infrastructure deployed, operational requirements, service performance requirements, topology of the deployed AIS service, etc).

For the SBAS based decentralised solution the assessment of the 'COM' and 'JSR' features depends on the data used for the reference station (SBAS SIS or EGNOS EDAS SISNeT service). For instance, in case of getting the SBAS data from the SIS, high availability communication lines are not needed ('COM') but the solution is not robust in front of jamming attacks. For that reason, the corresponding cells have been split to account for these two different options.

The particular details of these two architectures are described in the sections below

Key feature used for the assessment	Levels of implementation			Proposed Architectures – Trade Off Assessment	
	Improvement w.r.t. baseline	Baseline	Degraded w.r.t baseline	SBAS Centralised	SBAS Decentralise
Infrastructure at site (INF)	Reduced infrastructure	1 RS + 1 IM (external to the AIS Base Station)	Additional infrastructure		
Local effects impact corrections (LOC)	Local errors do not affect the differential corrections	Local errors, such as multipath, receiver noise or masking effects may affect the reference station	N/A		
Type of Communication lines (COM)	No communication lines	Standard communication lines (high-availability communication lines not needed)	High availability communication lines needed to ensure the IMO availability requirement		
VDL Monitoring (VDL)	The architecture includes the capability of monitoring the VDL radio link	The architecture does not include the capability of monitoring the VDL radio link	N/A		
Redundancy (RED)	There is redundancy at the RS or IM	There is no redundancy at the RS or IM	N/A		
Jamming and Spoofing Resiliency (JSR)	In case of jamming attack in the vicinity of the reference station, the DGNSS service will not be affected	In case of jamming attack in the vicinity of the reference station, the DGNSS service will be affected	N/A		
Customized corrections for each AIS Base Station (CUS)	Differential corrections are customized and generated for each AIS Base station	The same differential corrections are provided by several AIS Base stations	N/A		
Access to internal data (GNSS raw data or signal parameters) from the base or mobile station needed (INT)	N/A	No	Yes		

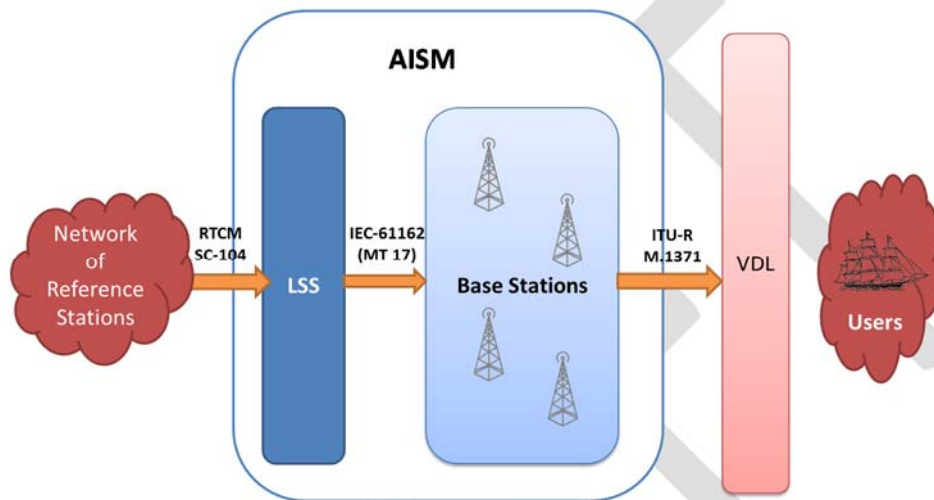
Table 3 *Key features and trade off assessment*

4.2.3. SBAS BASED DGNSS SOLUTION OVER CENTRALISED AIS SERVICE

This solution consists on generating the AIS Message 17 in a central facility (AISM) and distributes it to the different AIS base stations.

As depicted in the following figure, the DGNSS correction data from the reference station(s) is encapsulated in an IEC 61162 VDM sentence (discarding the preamble and parity fields) by the AIS Logical Shore Station (AIS-LSS) for processing by the AIS PSS Controlling Unit (AIS-PCU). The AIS Message 17 generated by the Logical Shore Station is then provided to each base station and finally transmitted to the users through the VDL channel.

Figure 9 *Classical DGNSS over AIS Centralised solution*



Considering the short coverage of the AIS base stations (within LoS range), a set of base stations is normally distributed alongside rivers, canals, coast and ports to cover the whole service area. On the other hand, taking into account that the range of a DGNSS station is in the order of 200 NM, the corrections generated by a reference station are normally used to feed multiple AIS base stations. This means that the same DGNSS corrections are transmitted by several AIS base stations.

By contrast, the SBAS corrections in RTCA format can be customized and converted into RTCM format for any location placed within the SBAS service area. Therefore, it is possible to generate RTCM data streams customised for each AIS base station and therefore provide DGNSS corrections for short baseline lengths.

In this way, the accuracy performance could be improved in comparison with the classical approach, in which the corrections generated by a reference station are used to feed multiple stations and therefore, the distance between the rover and the reference station (where the corrections are generated) can be much larger.

At very high level, the architecture of this solution would consist in:

1. **Central Facility (CF)**, responsible for the generation of the PRC corrections (including integrity).
2. **Monitoring Network**, providing GNSS data for the integrity monitoring check.
3. **AIS Service Manager (AISM)**, which retrieves the SBAS based DGNSS corrections in RTCM format and converts them in an IEC 61162 VDM sentence (discarding the preamble and parity fields) to be then distributed to the final users by the AIS base stations using the VDL channel.

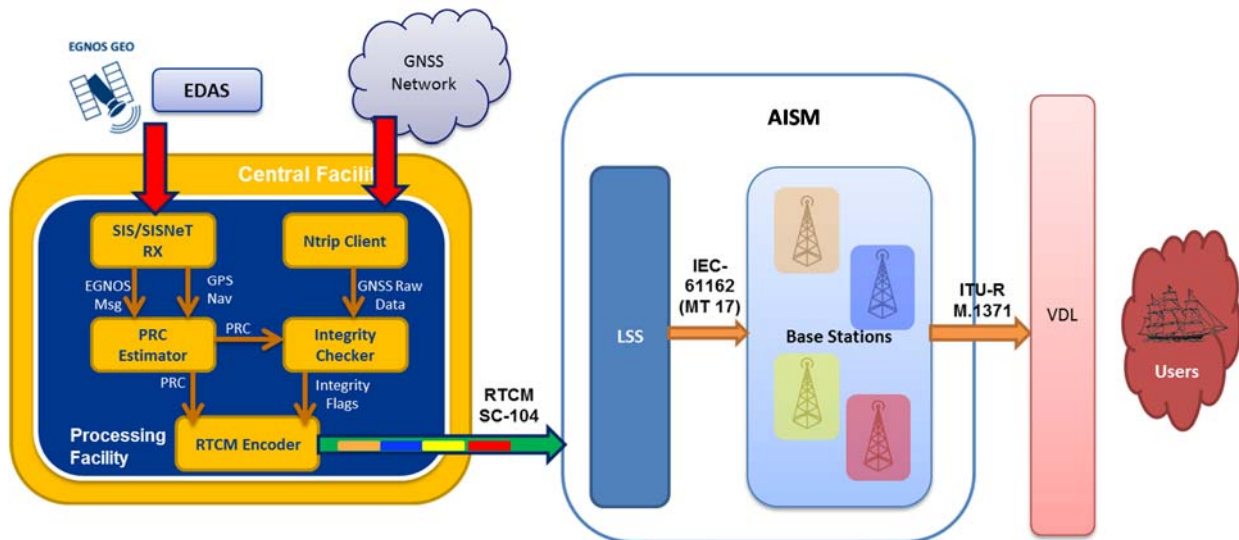


Figure 10 *SBAS based DGNSS corrections over AIS architecture*

A more detailed description of each of these components is provided below:

Central Facility

The Central Facility is the main component of a centralised SBAS based DGNSS service. The primary function of the Central Facility is to compute the Pseudorange Corrections for all the satellites above the elevation mask. PRCs and ancillary information (e.g. antenna location) are encoded into RTCM 10402.3 and transmitted to each beacon transmitter site.

The source for the generation of the DGNSS corrections to be broadcast by the transmitter could be the SBAS Signal in Space or the SBAS messages received from EGNOS EDAS service.

Monitoring Network

For the integrity monitoring check, the Central Facility needs to have access to GNSS measurements collected from a receiver located within the validity area of each set of DGNSS corrections.

One possibility is to have a dedicated network of GNSS receivers. These receivers shall be capable of transmitting (via internet) the raw data collected to the Central Facility.

Another option is to get the GNSS raw data (used for the integrity monitoring) from an existing network of GNSS receivers, when available⁹. The main disadvantage of this solution is that the AtoN provider needs to rely on an external entity, so it could be necessary (service provider decision) to establish a Service Level Agreement (SLA) to guarantee the reception of the data with the quality and availability required.

AIS Service Manager (AISM)

The RTCM corrections generated by the central facility are transmitted to the AIS Service Manager which converts them in an IEC 61162 VDM sentence (discarding the preamble and parity fields) to be then distributed to the final users by the AIS base stations using the VDL channel.

Internally to the AIS service (AISM or LSS) each corrections set will be routed to the target AIS Base Station (AIS-PCU).

It is important to remark that this component does not need to be modified with respect to a classical DGNSS solution. All the inputs/outputs are the same and in the same format, therefore, no change is

⁹ E.g. in europe http://www.epncb.oma.be/_networkdata/stationmaps.php

required. This means that the fact that the RTCM corrections are generated based on the SBAS message or by a classical DGNSS reference station is completely transparent for the AISM.

Regarding the trade-off assessment presented in Table 3, the analysis of the key features improved or degraded with respect to the baseline architecture is detailed hereafter.

- **Infrastructure reduction.** As mentioned before, no RS neither IM is needed at each AIS Base Station for the AIS Message 17 generation. Being possible therefore to reduce the HW and SW components needed at each station, with the consequent benefits in terms of deployment cost, power consumption, maintenance cost or operational procedures
- **Local effects & Multipath.** Local effects such as multipath, receiver noise or masking effects would have no impact on the quality of the corrections provided through the AIS #17 message.
- **Communication lines.** -Given that the present solution does not consider any local backup, high availability communication lines are required to connect the AISM with each AIS Base Station.
- **Jamming and Spoofing Resilience.** Considering that the SBAS-based corrections are generated and integrity checked in a central facility (not at each station), an eventual jamming or spoofing attack in the vicinity of the AIS Base Station would have no impact on the service.
- **Customized corrections for each AIS Base Station.** As detailed before, one of the advantages of the previous solution is that customised pseudorange corrections can be generated for each AIS Base Station, reducing the baseline distance between the rover position and the corrections reference.

4.2.4. SBAS BASED DGNSS SOLUTION OVER DECENTRALISED AIS SERVICE

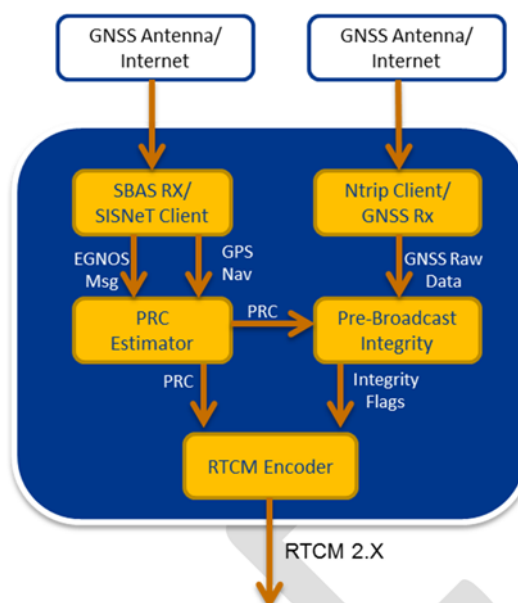
The source for the generation of the DGNSS corrections to be broadcast by the AIS station is the SBAS message.

The DGNSS corrections are provided as input (via a dedicated port) to the AIS Base Station, therefore, whether these corrections are received from a classical DGNSS stations or generated based on SBAS, is completely transparent for the AIS Base Station. Taking this into account, it is not necessary to do any change on the AIS Base Station but only on the external reference station and Integrity Monitoring (RS & IM). The external RS shall be replaced by a RS software to produce the differential GNSS correction taking the SBAS messages as input. This component would basically consist of an RTCA to RTCM converter (See ANNEX E). A pre-broadcast integrity monitoring concept could be implemented to check the integrity of the differential corrections generated by the SBAS based RS.

A block diagram of the resulting RS & IM, including both HW and SW components is included hereafter. It is to be noted that the SBAS message and the GNSS ephemeris can be obtained from an SBAS enabled receiver or from the EGNOS EDAS SISNeT service over the internet. Regarding the GNSS raw data needed to check integrity of the corrections, this data could be obtained from a dedicated GNSS receiver or from one of the different networks of receivers available (via internet/Ntrip).

In case of using, an SBAS enabled receiver to obtain the SBAS message (instead of the EDAS SISNeT service), it could be considered using the GNSS observations collected by this receiver to check the integrity of the data (note that the observations are not used to generate the differential corrections).

Figure 11 SBAS based AIS station: RS & IM block diagram



The corrections generated will be provided to the AIS Controller Unit in RTCM format (via the dedicated input port). Therefore, there will be no change with respect to the current interface, being the Controller Unit in charge of converting the RTCM message into VDL AIS #17 message format. As detailed above, it is important to remark that this solution is completely transparent for the base station itself, since it receives the corrections in RTCM format regardless they are generated by a classical reference station or converted from the SBAS message to RTCM format.

Finally, the rationale for the assessment presented in Table 3 is detailed below:

- **Local effects & Multipath:** Refer to the previous section.
- **Communication line:** In case the SBAS data is obtained from the SISNet service, high requirements concerning the availability and quality of the communication links are needed since there is no other backup available.
- **Jamming and Spoofing Resilience:** An eventual jamming or spoofing attack in the vicinity of the AIS Base Station would have no impact on the service in case of using the SISNet service to obtain the SBAS data and the GNSS ephemerids.

4.3. SBAS OVER OTHER DATA CHANNELS UNDER DEVELOPMENT SUCH AS VDES (VHF DATA EXCHANGE SYSTEM)

It has to be noted that the most of the considerations set out for AIS into this document are also applicable to the future developments of VDES (VDES includes the combination of AIS, ASM and VDE channels).

The VDES Technical and Operational requirements are being defined under the framework of the IALA ENAV WG3 at the time this guideline is being written.

VDES additional channels will be available solving some of the current limitations of AIS (e.g. channel load) and besides on the on board side the appropriate interfaces will be defined.

The definition of the VDES communication channels considers the possibility to broadcast SBAS corrections in RTCA format.

5. SBAS BENEFITS AND LIMITATIONS FOR THE SBAS USE VIA ATON

The use of SBAS- based solutions within the AtoN architectures provides several benefits including the following ones (depending on the specific implementation, architecture, scenario, etc.):

- **Infrastructure reduction at site** with the corresponding benefits in terms of deployment cost, power consumption, maintenance cost and operational procedures.
- For example in the case of the VRS centralized approach it is possible to optimize the on-site Reference Station and integrity monitoring HW (see section 4.1) with the associated cost savings.
- **Local effects & Multipath.** The only information needed for the generation of SBAS-based DGNSS streams is the SBAS message, time, and the GNSS ephemeris. The GNSS raw observations are not used and therefore, any local effects such as multipath or receiver clock jump/offset would not impact the quality of the corrections.
- **Jamming/spoofing resilience.** In line with the previous point, depending on the architecture design, an eventual jamming attack would have no impact on the SBAS-based solution. This could be achieved by obtaining the SBAS message and the GPS ephemeris from the EDAS SISNeT service or by having two SBAS enabled receivers in two different locations.

For the benefits previously pointed out (local effects and jamming/spoofing) it is noted that depending on the location of the GNSS receivers used for the integrity check, the IM module may be also affected and therefore the SBAS-based solution as well.

On the other hand there are several limitations including the following ones:

- **SBAS service areas are limited.** Currently SBAS services have regional coverage nevertheless the trend is SBAS services to expand their coverage areas in order maximize the service coverage over the globe. See 0.
- It also important to note that currently not all SBAS providers have declared a specific service for maritime use.
- **Satellites shadowing limiting the SBAS SiS access.** It can be scenarios where the AtoN (DGNSS, AIS, VDES) reference stations can be allocated in a place with limited access to the satellite SiS and therefore the SBAS use can be impacted.
- **Not direct control of the SBAS data by the AtoN provider.** SBAS services are not under the Maritime Authorities or Service providers direct control and therefore depending on the regulatory framework in some countries a working arrangement with the SBAS provider should be established to guarantee the appropriate service level. See operational aspects on section 5.

On top of that, for the SBAS-based corrections over AIS, the following limitations are to be considered:

- The potential **VDL loading** caused by DGNSS corrections transmission through AIS #17 message is to be considered by the AIS provider. It is noted that the estimated load for the transmission of SBAS corrections by one single AIS station is around 1% of VDL capacity [2] [32]. VDL load will increase in case of having several neighbouring AIS stations. This potential limitation is expected to be mitigated by the future VDE channels.
- Correction through AIS #17 message are not used by the main navigation receiver for SOLAS vessels¹⁰. However, it is used in inland waterways vessels and by the VTS.

¹⁰ There is a mandatory requirement for the class A AIS shipboard equipment to forward GNSS augmentation data received over AIS message 17 to the vessels navigation receiver (IEC61993-2), but there is no corresponding requirement for the ships main radionavigation receiver (IEC61108-1) to receive and utilize this information

6. OPERATIONAL ASPECTS

It must be considered that even if the source of data is SBAS, the performances requirements included at IALA recommendation 121 and guideline 1112 must be fulfilled.

The same recommendations related to operational aspects included at IALA guideline 1112 are to be considered in case of the SBAS use via AtoN, notably those addressing at least:

- Operation and maintenance
- Performance verification
- Publication of information

In order to ensure compliance with the guideline 1112, AtoN providers considering utilization of SBAS are recommended to consult the SBAS service provider and establish appropriate working arrangements. These working arrangements should include at least:

- Provision of Information related to the SBAS service degradation and maintenance activities
- Provision of Information related to the Service characteristics (Performances, coverage area, etc.)
- Establishment of a Liability scheme
- Provision of alarms/alerts procedure in relation with service degradations
- Commitment about the long term operation of the service

7. ACRONYMS

AIS	Automatic Identification System
AISM	AIS Service Manager
ASM	Application Specific Messages
AtoN	Marine Aid(s) to Navigation
ATU	Antenna Training Unit
CF	Central Facility
CS	Control Station
DGNSS	Differential Global Navigation System
DFMC	Dual Frequency Multiconstellation
DGPS	Differential Global Positioning System
EC	European Commission
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
EMRF	European Maritime Radionavigation Forum
ESA	European Space Agency
ESSP	European Satellite Services provider
GEO	Geostationary
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System



GPS	Global Positioning System
GSA	European GNSS Agency
HW	Hardware
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEC	International Electro technical Commission
IWG	Interoperability Working Group
IM	Integrity Monitoring
IMO	International Maritime Organization (UN)
kHz	Kilohertz
LoS	Line of Sight
LSS	Logical Shore Station (AIS)
MF	Medium Frequency (300 kHz to 3 MHz)
MFMC	Multifrequency Multiconstellation
Msg	Message
MSK	Minimum Shift Keying
MT	Message type (AIS)
NM	Nautical mile
Ntrip	Networked Transport of RTCM via Internet Protocol
PCU	PSS Control Unit (AIS)
PNT	Position, Navigation and Timing
PR	Pseudorange
PRC	Pseudorange Correction(s)
RHCP	Right-Hand Circularly Polarised
RIMS	Ranging and Integrity Monitoring Stations (SBAS)
RS	Reference Station
RSIM	Reference Station - Integrity Monitor
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Maritime Services
Rx	Receiver / Reception
SBAS	Satellite-Based Augmentation System
SiS	Signal in Space
SLA	Service Level Agreement
SW	Software
Tx	Transmitter / Transmission
UDRE	User Differential Range Error (GPS)
VDES	Very High Frequency Data Exchange System
VDL	VHF Data Link
VRS	Virtual Reference Station
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 1984 (Reference coordinate system used by GPS)

8. REFERENCES

- [1] IALA Guideline No. 1029 On Ship-Borne Automatic Identification System (AIS) Volume I Part II: Technical Aspects of AIS, Edition 1.1, December 2002
- [2] IALA Recommendation A-124 Appendix 16 – DGNSS Broadcasts from an AIS Service
- [3] IALA Recommendation A-124 Appendix 4 –Interaction and Data Flow Model December 2011
- [4] IALA Guideline No. 1112, Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz, Edition 1, May 2015
- [5] RTCM Standard 10401.2 for Differential Navstar GPS Reference Stations and Integrity Monitors (RSIM), December 18, 2006
- [6] RTCM 10402.3 Recommended Standards for Differential GNSS services, August 20, 2001
- [7] SISNeT User Interface Document, E-RD-SYS-E31-010, Issue 3, Rev. 1.
- [8] EDAS Service Definition Document, Issue 2.1, December 19 2014 (https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_edas_sdd_in_force.pdf).
- [9] Global SBAS Status - Interoperability Working Group (IWG) - June 2016
- [10] European GNSS Agency: <https://www.gsa.europa.eu>
- [11] GSA EGNOS portal: <https://egnos-portal.gsa.europa.eu/>
- [12] IMO Resolution A.1046 (27) on the World Wide Radio Navigation System (WWRNS).
- [13] MOPS DO-229D Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment, 12/13/2006
- [14] ENAV18-13.20 Transmission of SBAS corrections over IALA beacons
- [15] ENAV19-13.13 Relevant architectures for the transmission of SBAS corrections over existing maritime AtoN - two cases studies: IALA beacon and AIS
- [16] ENAV18-13.16 Transmission of SBAS corrections over AIS
- [17] ENAV18-13.20 Transmission of SBAS corrections over IALA beacons
- [18] SISNeT User Interface Document, E-RD-SYS-E31-010, Issue 3, Rev. 1.
- [19] EDAS Service Definition Document, Issue 2.1, December 19 2014
- [20] IALA Guideline No. 1053. The Submission of a DGNSS Service for Recognition as a Component of the IMO WWRNS Edition 1, IALA, December 2006
- [21] World Wide Radio Navigation Plan Edition 2, IALA, December 2012
- [22] IALA NAV Guide 2018
- [23] Revised maritime policy and requirements for a future GNSS, IMO A.915(22), 29 November 2001
- [24] IMO MSC.401 (95) Performance standards for multi-system Receivers
- [25] IALA NAV Guide 2014
- [26] GNSS Market Report Issue 5, April 2017.
https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf
- [27] GNSS Market Report Issue 4, March 2015. https://www.gsa.europa.eu/system/files/reports/GNSS-Market-Report-2015-issue4_0.pdf

- [28] GSA/ESSP Market Status and Adoption Plan 2016- 2017
- [29] SISNeT User Interface Document, E-RD-SYS-31-010, Version 3, Revision 1, 15/05/2006.
http://www.egnos-pro.esa.int/Publications/SISNET/SISNET_UID_3_1.pdf
- [30] Networked Transport of RTCM via Internet Protocol (Ntrip), version 1.0,
<http://www.rtcn.org/orderinfo.php>
- [31] IMO Guidelines for shipborne PNT (data processing). IMO MSC, 2017
- [32] IALA AIS Guideline 1029, Volume 1, Part 2
- [33] Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band, ITU-R M.1371-5
- [34] Generic Cost Analysis focus on relevant architectures for the transmissions of SBAS corrections over IALA beacon and AIS. ENAV-20.13.16

DRAFT

ANNEX A SBAS BASIC ARCHITECTURES

The main elements of a basic SBAS architecture are:

A. Space segment:

Includes the satellites with payloads aimed to transmit the corrections to the GNSS core constellations L1¹¹ and integrity information.

B. Ground segment:

Includes all the ground elements in charge of the provision of the SBAS navigation message. The main elements are:

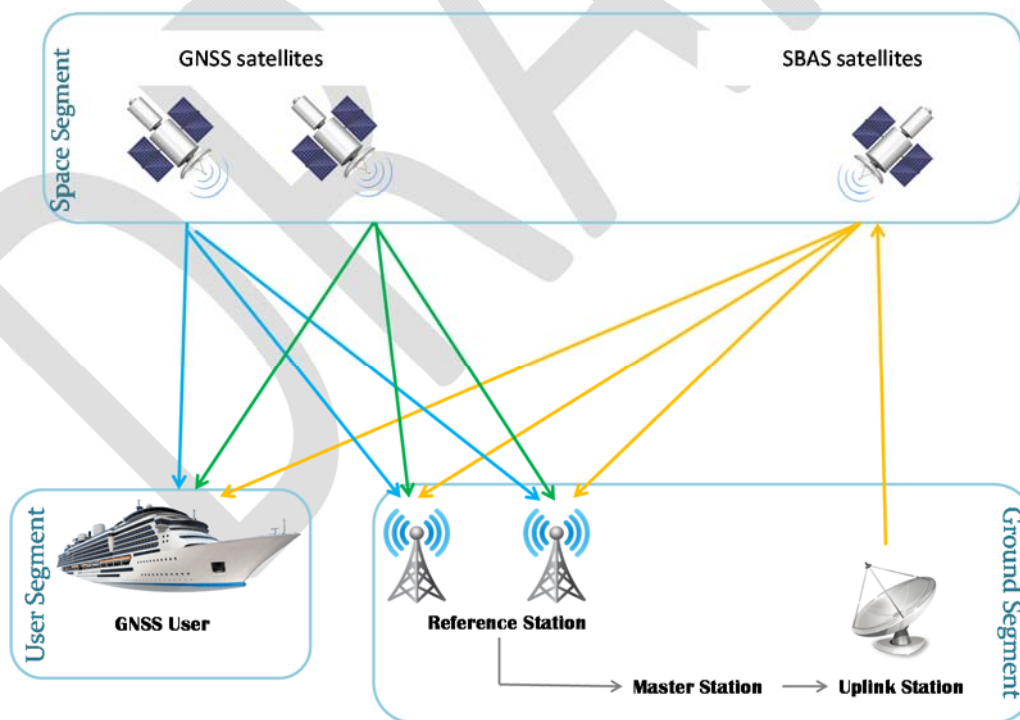
- Monitoring Station Network.
- Processing Facility Center.
- Satellite Control Center.
- Communication Layer.

C. User segment:

Includes the user equipment needed to receive and use the SBAS information.

The schematic basic functional architecture of an SBAS system is shown below.

Figure 12 *Basic SBAS Architecture*



¹¹ 1,575.42 MHz

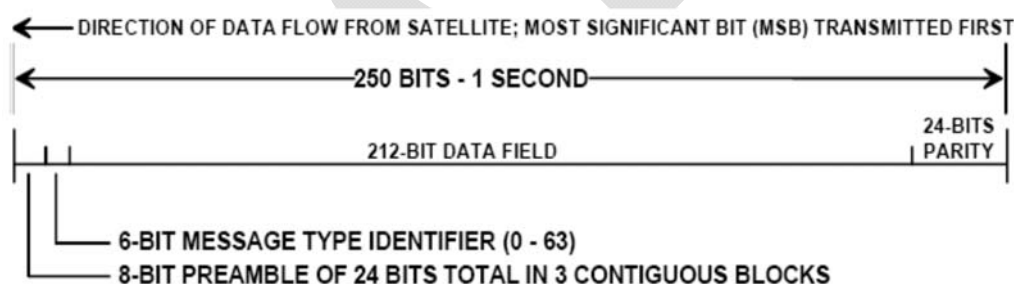
ANNEX B SBAS SIS AND MESSAGES

The basic SBAS SiS characteristics are:

- Frequency: 1575.42 MHz (L1)
- Polarization: RHCP
- Data rate: 250 bit per second
- Format summary: All messages shall consist of
 - Message type identifier
 - Preamble
 - Data field
 - Cyclic redundancy check

The broadcast signal is a combination of a 1023-bit PRN navigation code of the GNSS and a 250 bits per second navigation data message carrying the corrections and integrity data elaborated by the SBAS ground segment. The SBAS messages structure is schematically shown in Figure 13.

Figure 13 SBAS Messages. RTCA DO-229D



The content of each SBAS message type is summarized below:

Message Type	Contents	Purpose
0	Don't Use for Safety Applications	Discard any ranging, corrections and integrity data from that PRN signal for safety applications.
1	PRN Mask assignments	Indicates the slots for GPS and Augmentation satellites provided data
2-5	Fast corrections	Range corrections and accuracy
6	Integrity information	Accuracy-bounding information for all satellites in one message
7	Fast correction degradation factor	Information about the degradation of the fast term corrections

Message Type	Contents	Purpose
9 ¹²	Augmentation Satellite ranging function parameters	SBAS satellites orbit information (ephemeris)
10	Degradation parameters	Information about the correction degradation upon message loss
11	N/A	Reserved for future messages
12	SBAS network Time/UTC offset parameters	Parameters for synchronisation of SBAS Network time with UTC
13-16	N/A	Reserved for future messages
17	Augmentation satellite almanacs	Augmentation Satellite Almanacs
18	Ionospheric grid point masks	Indicates for which geographical point ionospheric correction data is provided
19-23	N/A	Reserved for future messages
24	Mixed fast/long-term satellite error corrections	Fast-term error corrections for up to six satellites and long-term satellite error correction for one satellite in one message.
25	Long-term satellite error corrections	Corrections for satellite ephemeris and clock errors for up to two satellites
26	Ionospheric delay corrections	Vertical delays/accuracy bounds at given geographical points
27	SBAS Service Message	Determines the δUDRE factor applicable in the Service Area.
28	Clock-Ephemeris Error Covariance Matrix	Relative covariance matrix for clock and ephemeris errors. Used to specify the correction confidence as a function of the user location.
29-61	N/A	Reserved for future messages
62	N/A	Reserved (Internal Test Message)
63	Null message	Filler message if no other message is available

Table 4 E.g. SBAS Messages RTCA DO-229D

The performance of the SBAS services is defined in terms of accuracy, integrity, continuity and availability.

¹² MT 9 is broadcast with some information about the orbital position of the broadcasting Augmentation satellite.

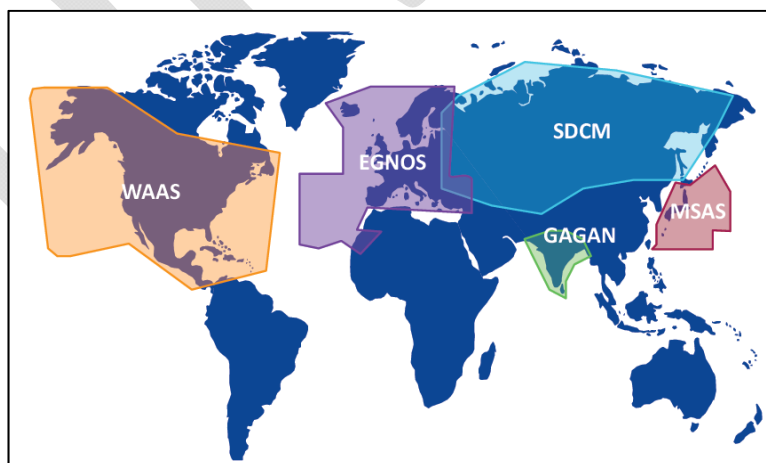
ANNEX C IDENTIFICATION OF THE DIFFERENT EXISTING SBAS SYSTEMS, COVERAGE AND PERFORMANCES

As depicted in the IALA NAVGUIDE 2014 section 4 [25] several countries and regions have implemented their own Satellite-based Augmentation Systems and related services.

- USA: Wide Area Augmentation System (WAAS)
 - https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/
 - <https://www.navcen.uscg.gov/>
- Europe: European Geostationary Navigation Overlay Service (EGNOS)
 - <https://egnos-portal.gsa.europa.eu/>
 - https://egnos-user-support.essp-sas.eu/new_egnos_ops/index.php
- Russia: System for Differential Corrections and Monitoring (SDCM)
 - http://www.sdc.ru/index_eng.html
- Japan: Multi-functional Satellite Augmentation System (MSAS)
 - http://www.kasc.go.jp/english/msas_01.htm
- India: GPS and GEO Augmented Navigation (GAGAN)
 - <http://www.isro.gov.in/>
- China: Satellite Navigation Augmentation System (SNAS). (in development)
- Republic of Korea: Korea Augmentation Satellite System (KASS). (in development)
 - www.kass-eng.re.kr

[10] presents schematically the Service coverage of the world's SBAS systems.

Figure 14 *SBAS systems indicative coverage¹³ (source GSA[10])*



¹³ The actual coverage area may vary slightly depending on the operation addressed, because it is directly linked to the target level of performance.

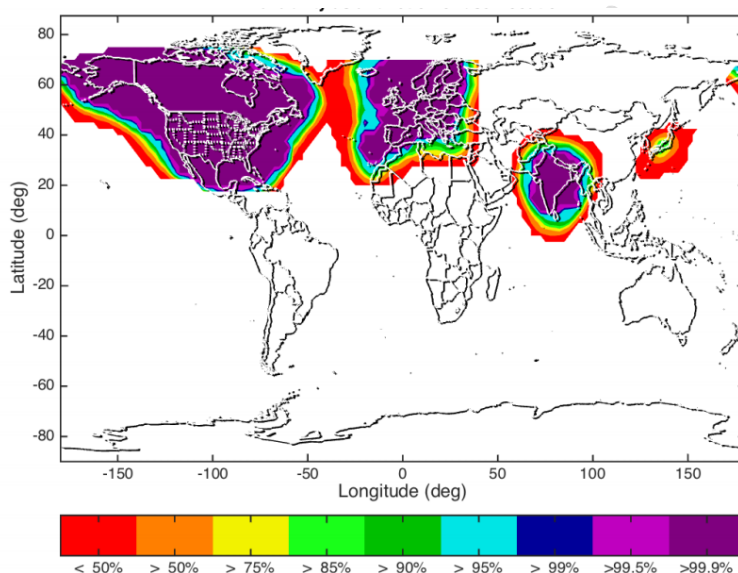
ANNEX D SBAS FUTURE DEVELOPMENTS AND TRENDS

The evolution of the SBAS services in the medium term will be mainly focused on the:

a) Extension of Service coverage (e.g. EGNOS V3, WAAS Phase IV)

With the intention to indicate the availability coverage of the worldwide SBAS Single Frequency Single constellation the figure below shows the current coverage maps.¹⁴

Figure 15 Availability map of Single Frequency, Single Constellation SBAS¹⁵



b) Implementation of the Dual Frequency Multiconstellation (DFMC) concept

The implementation of dual frequency services (e.g. L1 and L5) will make SBAS SiS fully robust against ionospheric gradients¹⁶.

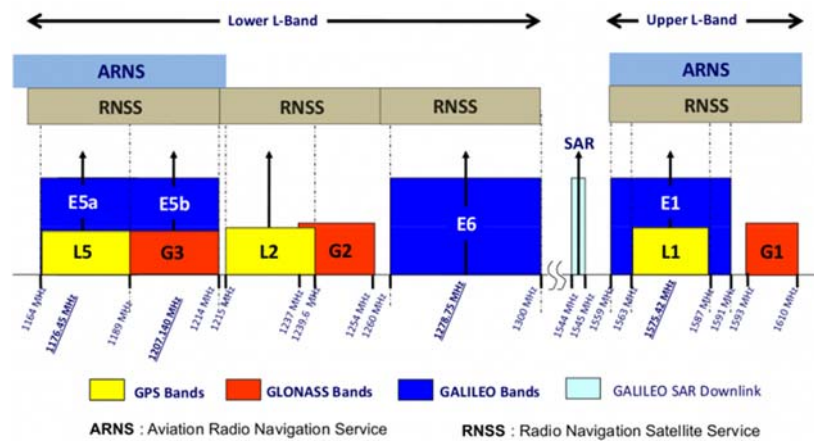
The following figure schematically shows the frequencies and bandwidths allocated to GPS, GLONASS, and Galileo.

¹⁴ Note that the availability map is just indicative and it is not taking into account IMO resolution A.1046.

¹⁵ Global SBAS status. IWG- June, 2016

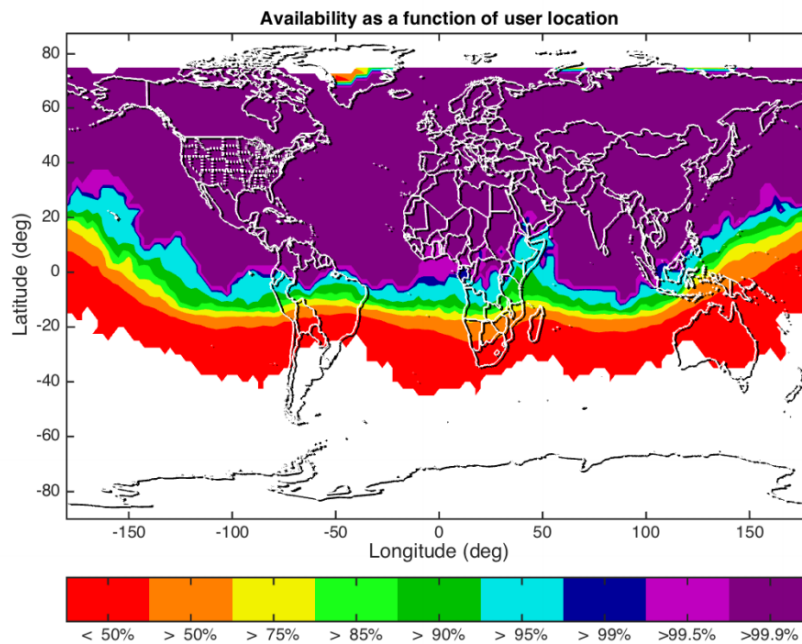
¹⁶ <https://pdfs.semanticscholar.org/2901/ed2ff1945a6236b4f440d95d639f6862496.pdf>

Figure 16 *Frequencies and bandwidths allocated to GPS, GLONASS, and Galileo*



As previously indicated the implementation of the SBAS DFMC concept will be deployed together with the Extension of the coverage areas as indicated in the following figure:

Figure 17 *Generic view of 2025 Coverage of Dual Frequency, Multiple Constellation (DFMC) SBAS¹⁷*



- c) Provision of improved SBAS availability and performance by direct mitigation of ionospheric signal delay.
- d) Combination/augmentation of measurements from two or more core GNSS constellations out of four (GPS, GLONASS, Galileo, BeiDou).
- e) Improvement of robustness against unintentional interference.

¹⁷ SBAS integrity: Current Status & Future Perspectives, Per Enge, Stanford University- January 21, 2016

ANNEX E MAPPING OF RTCA SBAS MESSAGES TO RTCM 2. X

This section provides a suggestion of how SBAS messages in RTCA format could be mapped into to RTCM 2.x format. It is not the intention to standardize the process but just to provide an illustrative example considering that different approaches could be implemented. Besides, the reader should note that this example is based on the RTCA MOPS [13] that currently only address GPS augmentation.

IALA DGNSS employs the principle that the main sources of error in satellite navigation (i.e. satellite clock errors, satellite ephemeris errors, tropospheric and ionospheric delay estimation errors) are highly correlated for two users located relatively close to each other. Differential GNSS corrections are computed by placing a reference station with a GNSS receiver at a known location, determining corrections to the satellite ranging signals, and broadcasting these corrections to users. This removes the bias errors common to the reference station and user receivers, and improves the positional accuracy. User receiver noise, inter-channel biases, user local effects and differential station location uncertainty then limit the accuracy.

SBAS is also providing corrections to the same errors (i.e. satellite clock, ephemeris errors and ionospheric delay estimation errors), with one exception: the troposphere. For this error source, SBAS systems do not provide corrections; the conversion process will apply a model to reduce the error in the position due to this effect. Taking this into account, the SBAS messages can be used for the generation of Virtual Reference Stations (VRS). The principle behind this solution would be to convert the wide area SBAS corrections in RTCA format, into local area corrections in RTCM SC-104 format for the locations of interest (e.g. beacon locations).

For the sake of clarity, the Pseudorange corrections provided by SBAS will be called from now on SBAS PRC, the Pseudorange corrections calculated by DGNSS reference stations will be called DGNSS PRC and the Pseudorange corrections calculated which map SBAS differential corrections into RTCM format will be called S-DGNSS PRC.

E 1 Pseudorange Rate Corrections for RTCM 2.X MT1/MT9

RTCM corrections can be reconstructed from SBAS provided data using the following equations:

$$PRC(t_{z-count}) = PRC(t_{of}) + RRC(t_{of}) \times (t_{z-count} - t_{of}) + \delta\Delta t(t_{z-count}) \times c + \varepsilon(t_{z-count}) + IC_i(t_{z-count}) + TC_i(t_{z-count})$$

Equation 1 Pseudorange rate corrections

Where:

$PRC(t_{z-count})$	is the RTCM MT1 PRC broadcast to the user
$PRC(t_{of})$	Is the most recent SBAS fast corrections MT2-5 and 25
$RRC(t_{of})$	Is the range rate corrections calculated according to equation A-17 in MOPS [13] Appendix A using the most recent fast correction and a previous one.
t_{of}	Time of applicability of the most recent SBAS fast correction
$t_{z-count}$	Reference time for the RTCM MT1 parameters
$\delta\Delta t(t_{z-count})$	SBAS clock correction from MT25 calculated according to MOPS Appendix A.
c	Speed of light 2.99792458×10^8 m/s
$\varepsilon(t_{z-count})$	SBAS ephemeris correction from MT25 projected to the radial direction user-satellite (line of sight). This radial ephemeris correction is inaccurate as it is kept the same value for the whole period of use of the S-DGNSS PRC. For a pure SBAS user applying MOPS, the radial ephemeris

correction is embedded in the satellite coordinate vector and therefore in the pseudorange calculation.

$IC_i(t_{z-count})$ Is the ionospheric delay calculated according to equation A-41 in MOPS Appendix A. Note this is always a negative value.

$TC_i(t_{z-count})$ Is the tropospheric delay calculated according to section A.4.2.4 in MOPS Appendix A. Note this is always a negative value.

The $\varepsilon(t_{z-count})$ maximum error induced should be estimated. Furthermore, this error contribution is present in the RRC computation below, so it will be somewhat compensated by the PRC estimation mechanism which uses this RRC. It is to be confirmed that the residual effect might then be dependent on radial acceleration only.

The provision of the $\varepsilon(t_{z-count})$ implies the need of the reference station to have track to that specific satellite. However, according to [5], DGNSS must send corrections to all satellites in view of the reference station. The satellites monitored by SBAS might be a different set of satellites than those in view from the DGNSS reference station. The corrections then shall be sent to the subset of GPS satellites monitored by SBAS and also in view from the station. For the GPS satellites in view by the reference station and not monitored by SBAS, the S-DGNSS PRC shall be set to 1000 0000 0000 0000 and the S-DGNSS RRC be set to 1000 0000, preventing the rover to use these satellites.

Upon the transmission of a new clock and ephemeris data from GPS, SBAS continues to broadcast corrections to the old long-term clock and ephemeris data for a period of 2 to 4 minutes so all the users can acquire the new GPS data. The corrections processor should consider this SBAS characteristic.

E 2 Range Rate Corrections for RTCM 2.X MT1/MT9

DGNSS Range Rate Correction (RRC) is an attempt to "extend the life" of the pseudorange correction as it "grows old" [5]. A possible S-DGNSS RRC could be calculated using the difference between the last calculation of SBAS PRC and a previous one available at the corrections processor.

$$RRC(t_{z-count}) = \frac{PRC(t_{current}) - PRC(t_{previous})}{\Delta t}$$

Equation 2 Range rate corrections

Where:

$RRC(t_{z-count})$ is the RTCM MT1 RRC broadcast to the user

$PRC(t_{current})$ Is the most recent S-DGNSS PRC calculated using the last set of SBAS fast corrections available and its correspondent SBAS slow corrections and, ionospheric corrections.

$PRC(t_{previous})$ Is a previous S-DGNSS PRC calculated using a previous set of SBAS fast corrections available and its correspondent SBAS slow corrections and ionospheric corrections.

$t_{z-count}$ Reference time for the RTCM MT1 parameters

$$\Delta t = (t_{current} - t_{previous})$$

The calculation proposed is in line with MOPS DO-229D. However, other approaches may yield better RRC performance. DGNSS receiver typically uses a proprietary RRC algorithms based on a second order filter.

As the update rate of SBAS fast corrections (typically six seconds) could be higher than the DGNSS MT1 update rate, note that the most recent S-DGNSS and a previous S-DGNSS PRC not necessarily are the last two S-DGNSS broadcast in MT1. The S-DGNSS PRC is a "snapshot" of the whole SBAS corrections in the reference station at a

specific epoch (slow, fast, ionosphere and troposphere), therefore the update rate might be selected by the reference station and there is no constraint from SBAS messages update rate.

E 3 S-DGNSS UDRE

According to [5], DGNSS UDRE is a one-sigma estimate of the uncertainty in the pseudorange correction as estimated by the reference station, and combines the estimated effects of multipath, signal-to-noise ratio, and other effects. The DGNSS UDRE is not used to provide integrity information just to weight the measurements and obtain a more accurate solution.

In the other hand, SBAS UDRE provides integrity information for the SBAS user and it only bounds the combined fast and long term corrections. The S-DGNSS UDRE concept should be in line with DGPS UDRE concept (and not the SBAS UDRE). The calculation can be done following MOPS Appendix J.

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,TROPO}^2$$

Equation 3 S-DGNSS UDRE

Where

- σ_i^2 S-DGNSS UDRE (squared) for an specific satellite at $t_{z-count}$
- $\sigma_{i,flt}^2$ Model variance for the long term, fast and range rate corrections as defined in MOPS Appendix A and J
- $\sigma_{i,UIRE}^2$ Model variance for the slant range ionospheric error as defined in MOPS Appendix A and J.
- $\sigma_{i,TROPO}^2$ Model variance for the tropospheric error as defined in MOPS section A.4.2.5.

Sigma value obtained will be coded according to Table 4-6 and scaled according to Table 4-2 in [5]. Sigma values could vary depending on the location and time but typical ranges could be around 1 m and 5m. DGNSS UDRE scale factors such as 0.3, 0.5 or 0.75 might be the most used.

E 4 S-DGNSS integrity alerts

SBAS sends integrity flags for GPS satellites. SBAS effective time to alert is 6 seconds. S-DGNSS must take advantage of the alert information broadcast by SBAS. S-DGNSS might set a satellite as “Do not Use” (DU) immediately using RTCM MT1 or MT9, if SBAS sets that satellite DU through SBAS MT6. For the specific satellite, the DGNSS MT1/9 PRC field shall be set to binary 1000 0000 0000 0000 [5] and MT1/9 RRC shall be set to binary 1000 0000 which indicates a problem and the User Equipment should immediately stop using this satellite.

Other possible situations when S-DGNSS must send an alert for a satellite are:

- When either the S-DGNSS PRC or the RRC is higher than the maximum range for PRC ($\pm 10485.44\text{m}$) or RRC ($\pm 4.064\text{m/s}$) allowed by RTCM MT1.
- When SBAS ionosphere corrections are not available for a satellite monitored by SBAS.

E 5 Summary S-DGNSS parameters

The parameters that must be included for each satellite in RTCM MT1/MT9 for S-DGNSS are:

S-DGNSS Parameter for DGNSS MT1	Derived in
UDRE	σ_i^2
PRC	$PRC(t_{z-count})$
RRC	$RRC(t_{z-count})$
ISSUE OF DATA	Issue of data of the GNSS navigation data being used. Also included in MT25 of MOPS Appendix A of MOPS Appendix A [13]

Table 5 *Derivation of S DGNSS*