|  |
| --- |
| IALA Guideline |

Based on the previous draft version of the working document (ENAV20-13.5 (ENAV19-14.2.4) Draft IALA Guideline Ed.1 Use of SBAS) this version includes the information presented and the feedback provided during the last ENAV19 meeting. We have revised and cleaned the document,

1???

The Maritime use of SBAS

Edition 1.0 (Draft)

Document date

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

|  |  |  |
| --- | --- | --- |
| Date | Page / Section Revised | Requirement for Revision |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

1. INTRODUCTION 5

2. SCOPE 5

3. DESCRIPTION OF SBAS 5

3.1. SBAS BENEFITS AND LIMITATIONS 5

3.2. IDENTIFICATION OF THE DIFFERENT EXISTING SBAS SYSTEMS, COVERAGE AND PERFORMANCES 6

3.2.1. Interoperability (IWG) 7

3.3. SBAS SERVICES DESCRIPTION AND STATUS, INCLUDING CURRENT USE OF SBAS BY THE MARITIME COMMUNITY 7

3.4. SBAS FUTURE DEVELOPMENTS EG. EXTENSION OF SBAS COVERAGES, NEW VERSIONS 8

4. POTENTIAL USE OF SBAS IN MARITIME 9

4.1. SBAS Signal In Space (SiS) 9

4.2. SBAS Data used via Internet 10

4.3. SBAS Data used via Maritime Service providers’ AtoN 10

4.3.1. SBAS over DGNSS messages (IALA Beacon) 10

4.3.2. SBAS over Automatic Identification System (AIS) 19

4.3.3. SBAS over other data channels under development such as VDES (VHF Data Exchange System) 27

5. CONSIDERATION ON HOW SBAS CAN BE USED IN A RESILIENT PNT SYSTEM 28

6. PRE-REQUISITE FOR THE ADOPTION OF SBAS 28

7. CONCLUSIONS 28

8. ACRONYMS 28

9. REFERENCES 29

List of Tables

Table 1 Key features (legend) used for the assessment 13

Table 2 Trade-Off Analysis - EGNOS over IALA beacons 14

Table 3 Key features (legend) used for the assessment 22

Table 4 Trade-Off Analysis - EGNOS over AIS 22

Table 5 Derivation of E\_DGNSS 41

List of Figures

Figure 1 SBAS systems coverage (source GSA[10]) 7

Figure 2 Generic view of the different SBAS transmission/reception options in the maritime sector 9

Figure 3 DGNSS Service Architecture: Classic and Network Approach [4] 11

Figure 4 Baseline/current IALA Architecture 12

Figure 5 Hybrid Decentralised Architecture: Traditional DGNSS + SISNeT Based 15

Figure 6 Hybrid Centralised Architecture: Traditional DGNSS + EGNOS Based VRS 17

Figure 7 Fully EGNOS Based Solution 19

Figure 8 Functional block diagram of an AIS base station [1] 20

Figure 9 SBAS based AIS station: RS & IM block diagram 24

Figure 10 Traditional DGNSS over AIS Centralised solution 25

Figure 11 DGNSS over AIS Network Configuration 25

Figure 12 EGNOS based DGNSS corrections over AIS architecture 26

Figure 13 Approach A with minimal infrastructure (referred as A.1) 31

Figure 14 Approach A with local integrity monitor (referred to as A.2) 31

Figure 15 Approach A with SBAS and marine beacon DGPS providing complementary services and back-up to each other (referred to A.3) 32

Figure 16 Approach A with SBAS data fed into the distributed approach (referred to as A.4) 33

Figure 17 Approach A with SBAS data fed into the distributed approach with back up option (referred to as A.5) 33

Figure 18 Approach B considered with the distributed architecture 34

Figure 19 Approach B considered with the hybrid architecture 34

Figure 20 Approach C: SBAS information (from SiS) used to provide a local backup at the transmitting site when using the VRS approach 35

Figure 21 Generic schematic for SBAS data re-broadcast over marine beacon infrastructure at the local broadcast sit 35

Figure 22 SBAS used for an additional integrity check for a classic architecture 36

Figure 23 SBAS additional integrity check for another configuration of the classic architecture 37

Figure 24 SBAS data employed in the distributed architecture as an additional integrity check (Approach E, SBAS data either from SiS or Internet). 37

# INTRODUCTION

GNSS have become the primary means of obtaining Position, Navigation and Timing (PNT) information at sea. Most of the vessels in the world (even in the recreational and leisure fields) are equipped with GNSS receivers (SOLAS carriage requirement). Nowadays, these users can take advantage of different augmentation systems such as DGNSS and SBAS, as they provide increased accuracy and integrity.

DGNSS is an essential component of the e-Navigation system. It has the potential to meet most accuracy requirements within e-Navigation, and to provide the integrity information which is lacking to GNSS while being vital for safety applications. DGNSS corrections currently are computed locally at a reference station (RS), with fully redundant equipment [4].

Satellite Augmentation Systems (SBAS) can provide an alternative source for such corrections that can be accessed either through the SBAS Signal in Space (SiS) or through the Internet (Data Access Service currently only available for EGNOS, the European SBAS). Furthermore, SBAS corrections are immune to possible local (RS) disturbances. They consequently have the potential to become at least the secondary source of corrections for any DGNSS reference station and to be part of a more robust, and redundant design.

# SCOPE

This document is a guideline for the use of SBAS in maritime domain. It describes SBAS applications and services envisaged and its contribution to achieve resilient PNT in the maritime domain.

Additionally, the intention is to provide reference information to the Maritime Authorities and AtoN Providers interested in providing SBAS Services, giving examples of potential uses and technical guidance.

# DESCRIPTION OF SBAS

Satellite navigation systems are designed to provide a positioning and timing service over vast geographical areas (typically continental or global coverage) with high accuracy performance. However, a number of events may lead to positioning errors. Satellite-Based Augmentation Systems (SBAS) are designed to augment the navigation system constellations by broadcasting additional signals from geostationary (GEO) satellites.

The SBAS concept is based on GNSS measurements by accurately-located reference stations deployed across an entire continent. The GNSS errors are then transferred to a computing centre, which calculates differential corrections and integrity messages which are then broadcasted over the continent using geostationary satellites as an augmentation or overlay of the original GNSS message. SBAS messages are broadcast via geostationary satellites able to cover vast areas.

For further details refer to the NavGuide [Section 4.8.3 Satellite Based Augmentation Systems].

## SBAS BENEFITS AND LIMITATIONS

According to the inputs from the different SBAS System providers [9], SBAS benefits extend beyond aviation to all modes of transportation, including maritime:

* SBAS service is available for free
* SBAS technology provides the opportunity to cover very large areas of airspace and areas formerly not served by other navigation aids.
* SBAS adds increased capability, flexibility, and often, more cost-effective navigation options than adding additional legacy ground-based navigation aids.
* In some cases, SBAS may support the decommissioning of ground-based Navigation Aids.
* SBAS benefits also extend to applications beyond aviation:
  + Proven enhancement of position accuracy wrt GPS on average in different environments
  + No extra costs in new systems (consumer-grade chipsets SBAS-enabled, just requiring a suitable configuration)
  + Enabling to enhance performance of present commercial applications using GPS
  + Capability to implement customized solutions for the delivery of added value services further exploiting SBAS features

SBAS Limitations: TBC

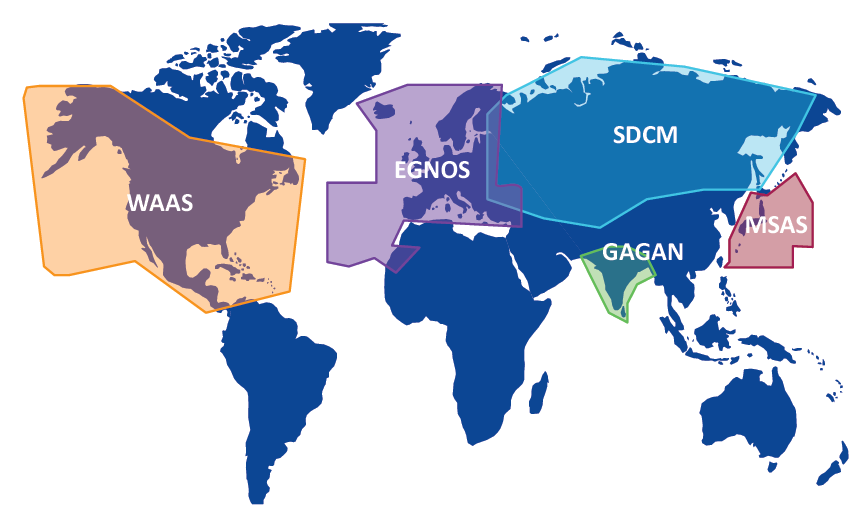
## IDENTIFICATION OF THE DIFFERENT EXISTING SBAS SYSTEMS, COVERAGE AND PERFORMANCES

Several countries have implemented their own Satellite-based Augmentation Systems. For example, in Europe EGNOS covers the majority of the European Union (EU), along with some neighbouring countries and regions. Other national SBASs include [10]:

* USA: Wide Area Augmentation System (WAAS)
* Japan: Multi-functional Satellite Augmentation System (MSAS)
* India: GPS and GEO Augmented Navigation (GAGAN)
* China: Satellite Navigation Augmentation System (SNAS) (in development)
* South Korea: Wide Area Differential Global Positioning System (WADGPSWADGPSWide Area Differential GPS) (in development)
* Russia: System for Differential Corrections and Monitoring (SDCM) (in development).

For further details, refer to the NavGuide [Section 4.8.3 Satellite Based Augmentation Systems].

Figure 1 presents schematically the coverage of the world’s SBAS systems.

[](https://www.google.es/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwiq9aivkufQAhXEbBoKHQ7FBUAQjRwIBw&url=https://www.gsa.europa.eu/european-gnss/what-gnss/what-sbas&bvm=bv.141320020,d.d2s&psig=AFQjCNE8CcdCu3GQJztBFUp_EPaLxmN60A&ust=1481373990504836)

1. SBAS systems coverage[[1]](#footnote-1) (source GSA[10])

EGNOS (European Geostationary Navigation Overlay Service) is the European satellite-based augmentation service (SBAS) that complements in Europe the existing satellite navigation services provided by the [Global Positioning System](http://www.navipedia.net/index.php/GPS_General_Introduction" \o "GPS General Introduction) (GPS). EGNOS is designed to broadcast a GPS-like signal in Europe with embedded corrections, providing improved performance over GPS. With EGNOS, all navigation receivers will benefit from enhanced accuracy, availability and continuity than is available with GPS only. Additionally, EGNOS provides integrity information about the GPS signals, disseminating information on the health of the GPS constellation and giving an alarm within six seconds in case of faulty positioning information.

EGNOS is the first element of the European satellite-navigation strategy and a major stepping-stone towards Galileo, Europe's future global satellite navigation system.

In the future, EGNOS system is expected to augment Galileo constellation as well as it does today to GPS. However, note that at this moment, for the options considered within this guideline EGNOS augments only GPS constellation.

### Interoperability (IWG)

To guarantee seamless and worldwide system provision, the existing SBAS systems meet common [standards](http://www.navipedia.net/index.php/SBAS_Standards" \o "SBAS Standards) and interoperability requirements. Therefore they are all compatible (do not interfere with each other) and interoperable (a user with a standard receiver can benefit from the same level of service and performance whether located in the EGNOS or WAAS coverage area). The service providers of the different SBAS systems meet regularly to conclude on the precise understanding of the term interoperability, and on the identification of the necessary interfaces among SBAS that each conceivable interoperability scenarios may imply.

## SBAS SERVICES DESCRIPTION AND STATUS, INCLUDING CURRENT USE OF SBAS BY THE MARITIME COMMUNITY

SBAS/EGNOS provides an important added-value not only when used in general navigation, but also in many other maritime applications, including SAR, homeland security and traffic management. Therefore, many maritime GNSS receivers used in the recreational and professional sectors are SBAS/EGNOS enabled.

However, the current introduction of SBAS in the maritime domain, even in the regulated sector, is limited, as the adequate regulatory framework needed for the provision of SBAS for the safety of navigation has not yet been put in place. In addition, specific implementation of SBAS in different maritime receivers is usually unknown, as there is not a SBAS/EGNOS standard for maritime receivers.

SBAS are often seen as new systems that could complement the maritime DGNSS service and may well provide additional capability to enable new applications. IALA World-Wide Radio Navigation Plan already foresaw SBAS as one of the available solutions for GNSS augmentation and, following the recent recognition of Galileo as part of the WWRNS (MSC 96th session), the EC and GSA are working on formally requesting the recognition of SBAS/EGNOS by IMO.

## SBAS FUTURE DEVELOPMENTS EG. EXTENSION OF SBAS COVERAGES, NEW VERSIONS

According to the Interoperability Working Group (IWG) of SBAS Systems, several evolutions are expected in the coming years [9]:

* GNSS Dual Frequency Operations;
* GNSS Multiple-Constellation Operations (Galileo, BeiDou);
* EGNOS and MSAS reference network expansion;
* SDCM and GAGAN become operational.

When these evolutions are completed it is though that the global SBAS coverage will suffer an increase from the actual 7.54% at 99% (only WAAS, EGNOS and MSAS) to 92.65%, considering the use of multiple-constellation (GPS and Galileo)[9].

# 

# POTENTIAL USE OF SBAS IN MARITIME

SBAS data may be received by the mariner through various communication methods, with each method resulting in a different level of standardization, legislation and number of organizations involved. The following options are considered and shown in Figure 2:

* SBAS Data used form GEO Satellites (Signal in Space);
* SBAS Data used via Internet ;

For the moment this service is only available for EGNOS (EDAS [8]).

* SBAS Data used via Maritime Service providers’ AtoN.

In this approach, SBAS data is provided to the mariner over an existing marine radio service currently used for a recognized Aid to Navigation, such as marine beacon 300kHz and VHF frequencies used for AIS. In this case, two options are considered for the access to the SBAS data: SiS and Internet.

1. SiS: the source for the generation of the DGPS corrections (RTCM 2.x) to be broadcast by the (IALA beacon or AIS) transmitter is the SBAS Signal in Space.
2. Internet (EDAS): the source for the generation of the DGPS corrections (RTCM 2.x) to be broadcast by the (IALA beacon or AIS) transmitter is the EGNOS message received from EDAS.



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

## SBAS Signal In Space (SiS)

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

The main advantage to this option is the availability of an augmentation solution even in areas where DGNSS is not deployed or is out of the range of maritime users. In addition, this solution has no cost for AtoN providers, as the SBAS service is provided free of charge.

The current SBAS systems provide integrity at system level and the required accuracy for navigation in coastal waters, harbour approach and harbour entrances, as required by IMO regulation in Resolution A.1046(27)[12].

However, although SBAS/EGNOS is commonly supported by most GNSS receivers, there is currently 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 unified, meaning there is a potential that SBAS messages might be processed differently. In this regard, IMO NCSR has developed of a Multisystem Receiver Performance Standards including SBAS. This work is being completed with the definition of Guidelines for shipborne PNT (data processing) unit by an IMO Correspondence Group, and will be followed by the development of the appropriate IEC Test Specification, using the work being carried out in RTCM:

* RTCM SC-104 is working in the development of an SBAS standard for Shipborne Receivers.
* RTCM SC-131 is working in the development of the Multisystem Receiver standard.

More so, in order to guarantee an adequate level of service for the maritime users (e.g. the official publication of the service characteristics), other aspect as the provision of performance reports and Maritime Safety Information or the establishment of working agreements with the Administrations providing AtoN services, are being addressed by dedicated for a involving GNSS and Maritime experts.

## SBAS Data used via Internet

Currently the EGNOS Data Access Service (EDAS) provides data to the user in real time via an Internet connection, and provides several different data services, depending on the application. In general, available data includes raw GPS measurements observed at the EGNOS Ranging and Integrity Monitoring Stations (RIMS) and the same data/messages as provided from the EGNOS Geostationary Satellites[8].

The mariners could use data from EDAS directly onboard the vessels (e.g. via a shore-to-ship or satellite broadband link). Such a service could be used when it is not possible to receive data directly from the satellites, either due to obscuration or other issues with the receiving antenna. This approach does require good communications links (high availability). Additionally changes onboard would be necessary: new receiver equipment, EDAS client, link with the bridge equipment,…

A different approach would be to use EDAS as a potential source for the EGNOS information to be transmitted over existing Maritime AtoN (AIS or DGPS stations), as explained in the section below.

## SBAS Data used via Maritime Service providers’ AtoN

This section considers the transmission of SBAS information to an AtoN provider, which then retransmits it over AIS or DGPS stations. Therefore, two subcategories are presented:

* Transmission of SBAS corrections over DGPS stations (IALA beacons)
* Transmission of SBAS corrections over AIS stations

Note that, although this Guideline addresses the generic maritime use of SBAS, the analysis presented in the sections below has been done for EGNOS (European SBAS). Some of the results of the analysis, related to the the use of SiS, could be also applied to other SBAS. However, the solutions considering the use of SBAS messages through Internet (currently only available for EGNOS) would need to be reassessed for other SBAS.

### SBAS over DGNSS messages (IALA Beacon)

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 repair.



1. DGNSS Service Architecture: Classic and Network Approach [4]

The information presented in the sections below explains the possible functional ways to integrate SBAS data into these architectures, although there are technical questions and issues to resolve in order to do so.

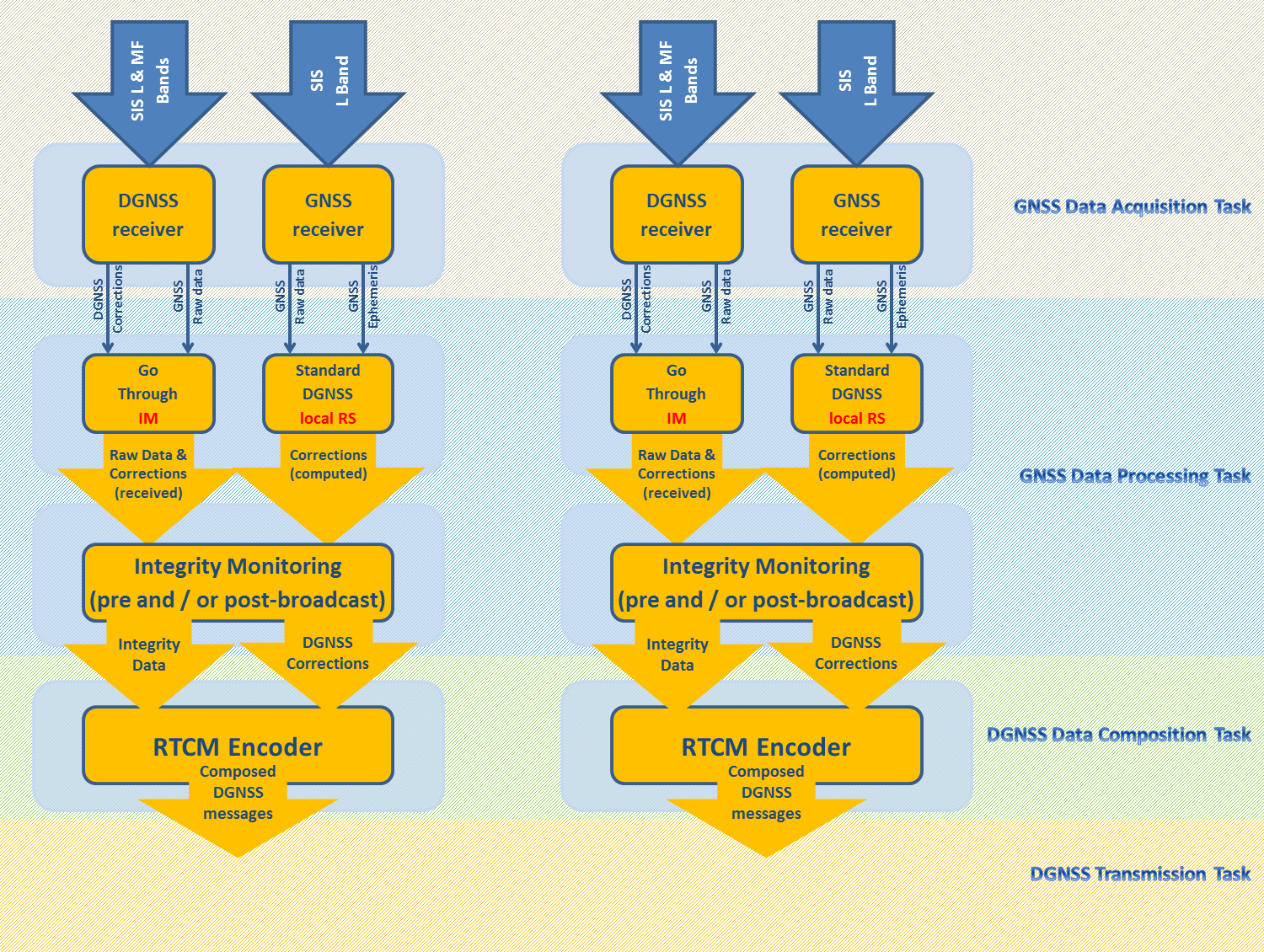
A detailed assessment of different architectures has been performed. The objective of this analysis is to identify the most promising SBAS based architecture(s) to be considered for deployment in an operational environment.

The starting point for this analysis has been to select a traditional baseline architecture used as a reference for the analysis. Then, a lower level detail analysis of several SBAS based architectures has been performed, comparing each architecture to the traditional DGNSS architecture (see baseline).

#### Baseline architecture

For a better understanding of the added value of the analysed solutions and of their potential drawbacks/limitations, a comparison with respect to a traditional baseline architecture has been performed. This baseline architecture has been defined as a DGNSS service based on the classic approach (IALA Guideline 1112[4]), the IALA recommended architecture of an IALA DGNSS station, including the Reference Station (RS) and the Integrity Monitoring (IM) modules. 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 an IALA DGNSS service.

It is also noted that this architecture is commonly doubled in order to meet the availability requirements defined by IMO Resolution A.1046[12].



1. Baseline/current IALA Architecture

As depicted in Figure 4, the Reference Station component computes the pseudorange corrections based on the GNSS raw data (observations and ephemeris) collected by a GNSS receiver (including the GNSS antenna) 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 DGNSS corrections collected by a DGNSS receiver. It is to be noted that the “DGNSS receiver” box depicted in the figure includes: GNSS antenna, MF antenna and MSK demodulator (MF receiver).

This architecture allows both Pre-Broadcast and Post-Broadcast Monitoring concept. 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.

#### Trade-off analysis

In order to identify the most promising DGNSS&EGNOS based architectures, a trade off analysis has been done, considering the following key features:

* Infrastructure at site.
* Legacy receivers compatibility.
* Integrity monitoring.
* Local effects impact corrections.
* Independence of corrections generation vs integrity check.
* Communication lines.
* MF link monitoring.
* Redundancy.
* Jamming and Spoofing Resiliency.
* Corrections generation separated from the transmission technology.

The features listed above, derived from the baseline architecture, are included in the next table with the key used for the analysis which 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.

| **Key feature** | **Key used for the Assessment** | | |
| --- | --- | --- | --- |
| **Improvement w.r.t. baseline** | **Baseline** | **Degraded w.r.t baseline** |
| 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 |
| Independence of corrections generation  vs integrity check (IND\*) | N/A | Independence between the data used to generate the corrections and the data used to check the integrity of these corrections | Same data us for the corrections generation and the integrity check |
| 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 |

1. Key features (legend) used for the assessment

Note that there are several architectures for which the assessment of the key features depends on the data used for 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 EGNOS based architecture. In that case, the corresponding cell has been split to account for the two possible options (see Table 2 below).

Among the identified criteria, the following are considered to be mandatory or highly recommended for an EGNOS based architecture to be presented to the maritime authorities as an alternative to their current solutions:

* The “Legacy onboard receivers compatibility” (LEG) and “Integrity Monitoring” (IM) functionalities are considered mandatory (highlighted in red in the table). Therefore, EGNOS based DGNSS service architectures requiring new user equipment are proposed to be discarded.
* The following IALA/IMO recommendations that should be considered when designing an EGNOS based DGNSS architecture (highlighted with an asterisk (\*) in the tables):
  + Independence of corrections generation vs integrity check
  + MF link monitoring
  + Corrections generation separated from the transmission technology
* Moreover, in order to meet the availability requirement (99.8%) for general maritime navigation, redundant solutions should be considered (as the baseline architecture).

Taking this into account, among the solutions analysed (see ANNEX A), only 3 met the mandatory features and recommendations mentioned above and have been retained for further consideration. These are:

* Hybrid Decentralised Architecture: Traditional DGNSS + SISNeT Based
* Hybrid Centralised Architecture: Traditional DGNSS + EGNOS Based VRS
* Redundant Fully EGNOS Based Solution

The table below presents the trade-off analysis performed for these three identified architectures:

| Title | INF | LEG | IM | LOC | | IND(\*) | COM | MF(\*) | RED | JSR | | SEP(\*) | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Hybrid Decentralised |  |  |  |  |  |  |  |  |  |  |  |  | |
| Hybrid Centralised |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Redundant fully EGNOS |  |  |  |  | |  |  |  |  |  | |  |  |

1. Trade-Off Analysis - EGNOS over IALA beacons

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 (EGNOS enabled or not), among other technical aspects and also any relevant operational/service requirement provided by the target maritime authority.

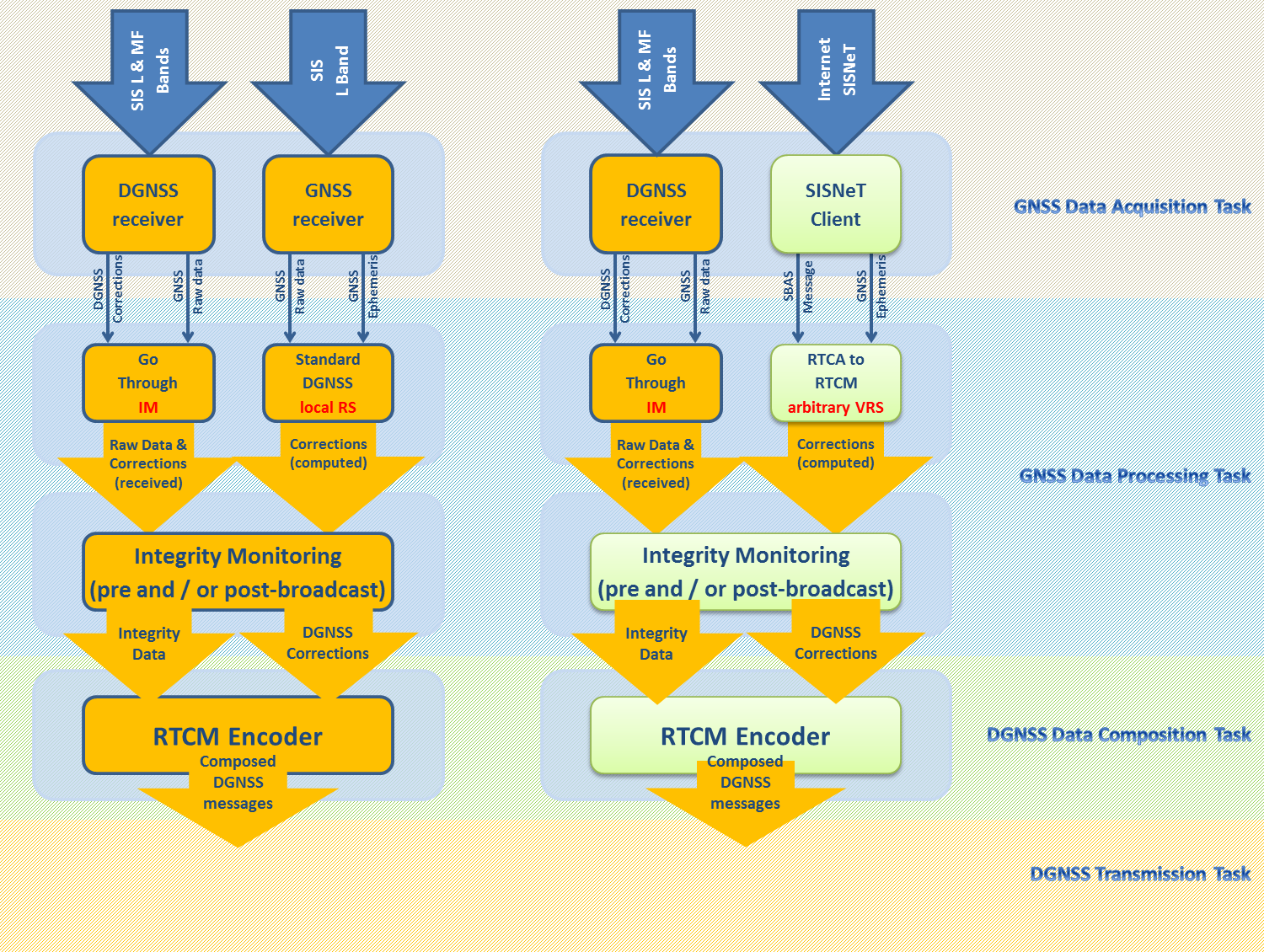
The particular details of these three architectures are described in the sections below.

#### Hybrid Decentralised Architecture: Traditional DGNSS + SISNeT Based

This is a redundant decentralised solution, combining the traditional DGNSS configuration and the EDAS (SISNeT)[8] based architecture which counts on two RS and two IM locally onsite.

The two IM parts (including the IM SW module and the DGNSS receiver) are identical and in line with the current architecture while for the second RS part, as depicted in the following figure, the GNSS receiver and the standard reference station are replaced by a SISNeT Client and a RTCA to RTCM converter. Please note also that all the components highlighted in the following figure (SISNeT Client, RTCA to RTCM converter, Integrity Monitoring and RTCM encoder) could be integrated in a single SW module. This module will be responsible for:

* Getting the SBAS corrections and GPS ephemeris from the EDAS SISNeT server.
* Converting the SBAS messages into DGPS 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.



1. Hybrid Decentralised Architecture: Traditional DGNSS + SISNeT Based

Please note also that 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 traditional architecture (left chain in the figure) could be used by the integrity monitoring module of the EGNOS based solution (right chain).

A variant for this architecture is to replace the SISNeT client by a GNSS antenna and an SBAS enabled receiver. In that case, internet connectivity will not be needed in the reference station, but more equipment will be required (GNSS antenna and SBAS receiver) at each beacon site.

It should be noted that, when connecting to EDAS SISNeT service, one has to choose between the two operational EGNOS GEO satellites. Hence, in order not to penalize the availability of the GPS corrections with respect to the option based on the access to the EGNOS messages through the SIS (SBAS compatible receiver is capable of tracking multiple GEOs), 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.

The IM will remain unchanged: all inputs/outputs are the same w.r.t the baseline 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 DGPS receiver to access the GPS measurements from the satellites.

#### Hybrid Centralised Architecture: Traditional DGNSS + EGNOS Based VRS

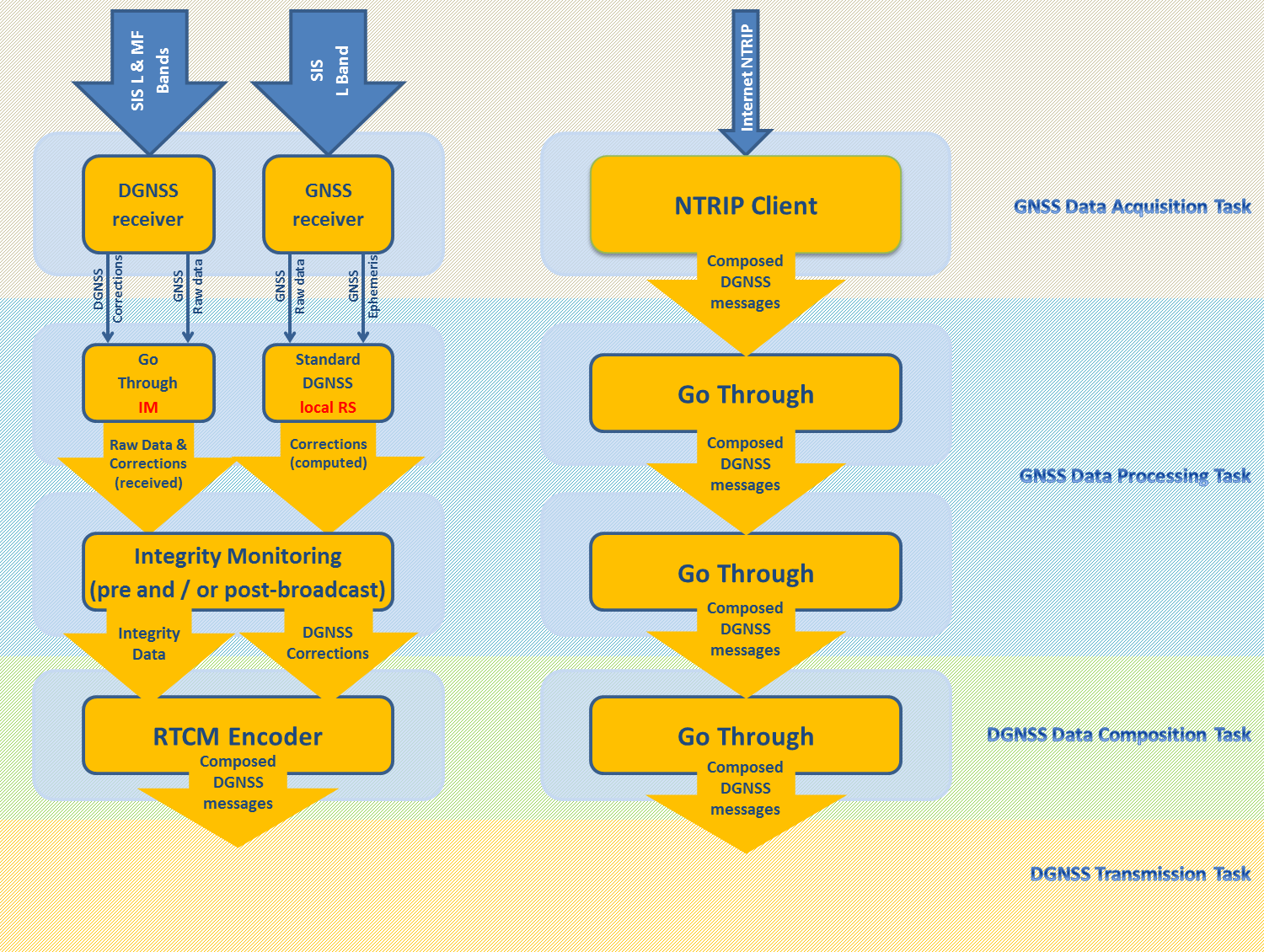
This solution combines a traditional DGNSS station deployed at each beacon site with a centralised EGNOS based VRS solution.

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 and the transmission equipment (apart from the EDAS Ntrip client[8] to retrieve the differential corrections).

The EGNOS 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 or the IM of the left branch (knowing that in that case the IM should be shared between the left and right braches).

It is to be noted that the DGNSS and GNSS receivers in the traditional DGNSS architecture (left chain in figure below) could be also used to monitor the signal and corrections transmitted by the EGNOS based solution (right chain in the figure below).

Finally, it is important to remark that apart from the reduction of HW/SW components of the EGNOS 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 traditional reference station will not be able to collect GNSS raw data and therefore not able to generate differential corrections. However, the EGNOS based VRS solution will not be affected by this attack.



1. Hybrid Centralised Architecture: Traditional DGNSS + EGNOS Based VRS[[2]](#footnote-2)

The EGNOS Central Facility computes 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 [6] and transmitted to each beacon transmitter site. This EGNOS Central facility is composed of the following modules:

* **SISNeT Receiver**: EDAS SISNeT Service, providing access to the EGNOS GEO satellites messages transmitted through internet using the SISNeT protocol. This 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. As commented before, 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.

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.

* **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;
  + GPS Navigation message: GPS ephemeris are provided by the SISNeT receiver and are used to perform the RTCA to RTCM conversion;
  + SBAS corrections in RTCA format.

Therefore, for each VRS, the PRC estimator needs to compute the number of GPS satellites in view (based on the navigation message) and for each LoS estimate the pseudorange correction based on the orbit, clock and ionospheric corrections provided in the EGNOS message and other static information (tropospheric models). The ‘PRC Estimator’ module will also map the SBAS integrity alerts into RTCM 10402.3 (see ANNEX B in this document).

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

* **The Integrity Checker**: implements the classical **pre-broadcast integrity** concept by applying the E-DGNSS corrections to the GPS 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).

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 (GPS measurements) from the receivers and distribute this data to the Integrity Checker module.

The Integrity Checker, using as input the E-DGNSS corrections previously generated, the raw data collected by the Monitoring Network and known information (Receiver position, maximum acceptable error per line of sight after applying corrections –UDRE-), checks the integrity of the corrections both at the Position and the Pseudorange domains.

* **RTCM Encoder:** finally, the E-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.

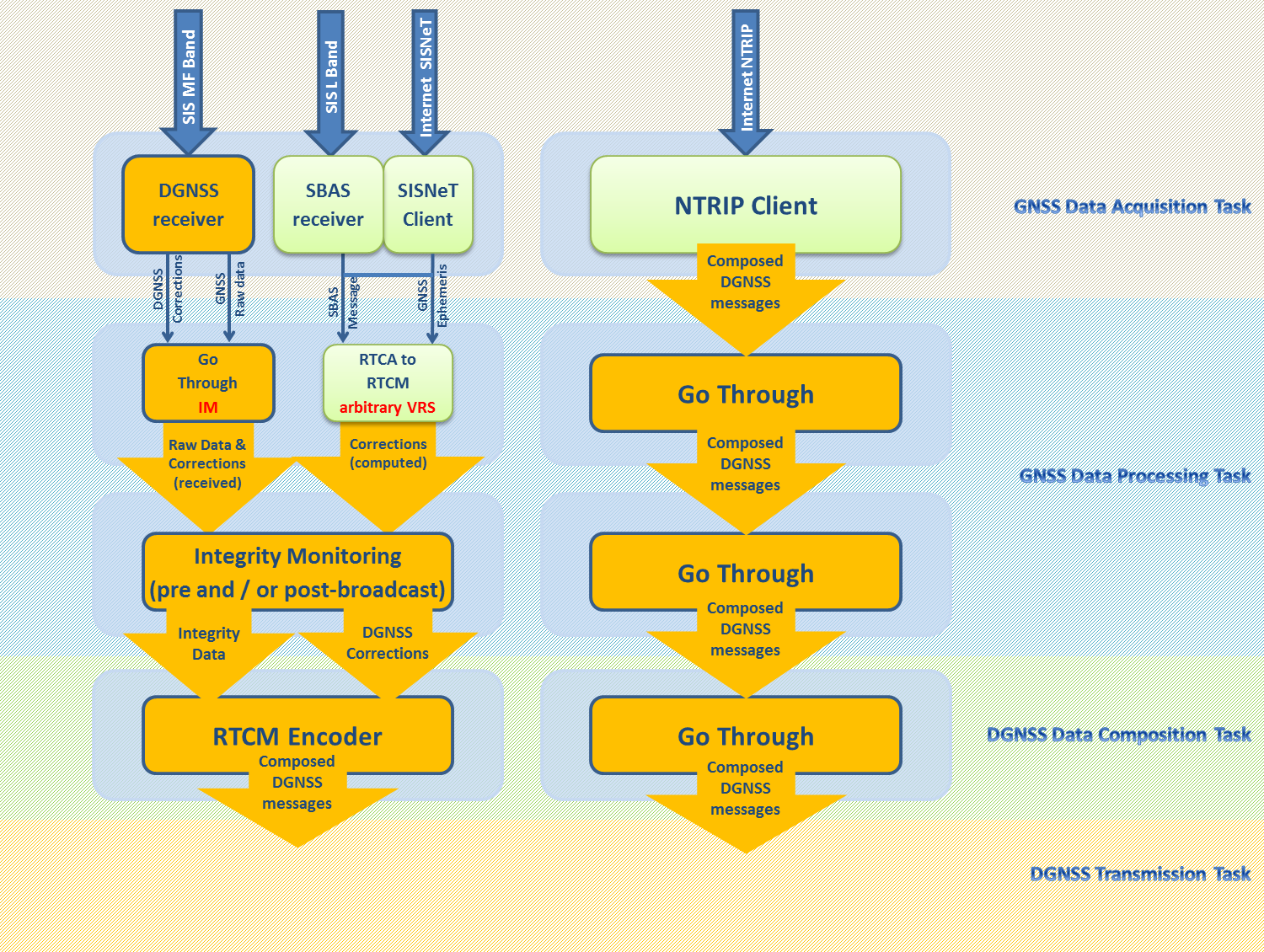
#### Redundant Fully EGNOS Based Solution

This is a fully EGNOS 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 a SISNeT client or from an SBAS enabled receiver.

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 EGNOS based centralised solution (right chain).

In order to eliminate a single point of failure, it is recommended to use two independent RTCA to RTCM SW solutions in the decentralised architecture (left chain) and the centralised architecture (right chain).



1. Fully EGNOS Based Solution

### SBAS over Automatic Identification System (AIS)

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 Message Type 17), including the definition of a high-level architecture, functional elements and interfaces. The architectures presented in this section have been defined avoiding any impact on the internal components/elements of the AIS service.

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: ‘any stand-alone DGNSS reference station used by an AIS shore-station would need integrity monitoring’ [1].

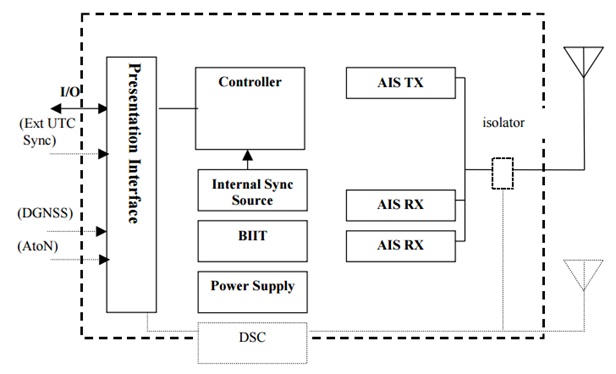
A detailed assessment of different architectures has been performed. The objective of this analysis is to identify the most promising SBAS based architecture(s) to be considered for deployment in an operational environment.

The starting point for this analysis has been to select a baseline architecture used as a reference for the analysis. Then, a lower level detail analysis of several SBAS based architectures has been performed, comparing each architecture to the baseline, which is described below.

#### 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, is provided. This choice has been made under the assumption that the ultimate goal of the study is to analyse the added value that SBAS/EGNOS could provide for the provision of DGNSS corrections over AIS.

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 traditional DGNSS reference station. It is also assumed that standard communication lines are available at the AIS base station. These 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.



1. Functional block diagram of an AIS base station [1]

#### Trade-off analysis

A low level detail analysis of several SBAS based architectures has been done, comparing each architecture with respect to the baseline one. In this trade-off analysis, the following key features have been considered:

* Infrastructure at site.
* Local effects impact corrections.
* Independence of corrections generation vs integrity check.
* Communication lines.
* VDL Monitoring.
* Redundancy.
* Jamming and Spoofing Resiliency.
* Corrections generation separated from the transmission means.
* Customized corrections for each AIS Base Station.
* Access to internal data (GNSS raw data or signal parameters) from the base or mobile station needed.

The assessment has been done taking into account these features (described in the table below) derived from the baseline architecture and using the following key (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, provide integrity monitoring. For that reason, the “integrity monitoring” capability has not been included in in the trade-off analysis, since there is no difference among the architectures addressed.

| **Key feature** | **Key used for the Assessment** | | |
| --- | --- | --- | --- |
| **Improvement w.r.t. baseline** | **Baseline** | **Degraded w.r.t baseline** |
| 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 |
| **Independence of corrections generation vs integrity check (IND)** | N/A | Independence between the data used to generate the corrections and the data used to check the integrity of these corrections | Same data us for the corrections generation and the integrity check |
| 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 |
| Corrections generation separated from the transmission means (SEP) | Yes | No | 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 |

1. Key features (legend) used for the assessment

Among the key features used for the analysis, two of them are considered to be mandatory or highly recommended to be met by any EGNOS based architecture to be proposed for deployment in an operational environment:

* The “**independence of corrections generation vs integrity check**” feature comes from an IALA recommendation**Error! Reference source not found.** [4] stating that the data used to check the data integrity shall be independent from the data used to generate the pseudorange corrections.
* The **access to the data collected by the internal GNSS receiver**. According to the consulted information for already existing AIS infrastructures (commercial AIS base stations), access to the data collected by the internal receiver (GNSS raw data or signal parameters) is not possible without changing the interfaces of the AIS Base or Mobile Stations. On those scenarios, where the AIS infrastructure is already deployed, it is recommended to use an external receiver to collect the data needed to compute the pseudorange corrections and check the integrity. Given this limitation, the architectures for those cases where already existing infrastructures cannot be (partially) reused are to be discarded.

Taking this into account, among the solutions analysed (see ANNEX A), the ones meeting the mandatory features and recommendations mentioned above are:

* EGNOS based DGNSS solution over decentralised AIS service.
* EGNOS based DGNSS solution over centralised AIS service.

The table below presents the trade-off analysis performed for the indicated architectures:

| Title | INF | LOC | IND | COM | | VDL | RED | JSR | | CUS | INT |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Baseline |  |  |  |  | |  |  |  | |  |  |
| EGNOS based decentralised |  |  |  |  |  |  |  |  |  |  |  |
| EGNOS based centralised |  |  |  |  | |  |  |  | |  |  |

1. Trade-Off Analysis - EGNOS over AIS

For the EGNOS based decentralised solution the assessment of the ‘COM’ and ‘JSR’ features depends on the data used for the reference station (SIS or 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.

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

In case the AIS shore infrastructure is developed from scratch, the base stations can be customised and equipped with additional functionalities (technically, cost impact unknown at this stage).

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

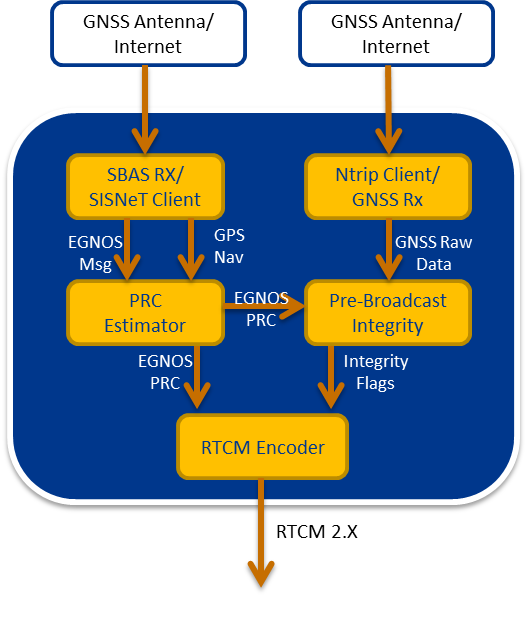
#### EGNOS based DGNSS solution over decentralised AIS service

In this case, the source for the generation of the DGPS corrections to be broadcast by the AIS station is the SBAS message, either obtained from the SBAS SIS or from the Internet (EGNOS EDAS), if available.

The DGNSS corrections are provided as input (via a dedicated port) to the AIS Base Station, therefore, whether these corrections are received from a traditional 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 GPS correction taking the SBAS messages as input. This component would basically consist of an RTCA to RTCM converter. 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 GPS ephemeris can be obtained from an SBAS enabled receiver or from the 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).

Also, in case of using an SBAS enabled receiver to obtain the SBAS message (instead of the EDAS SISNeT service), it could be considered to use 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).



1. SBAS based AIS station: RS & IM block diagram

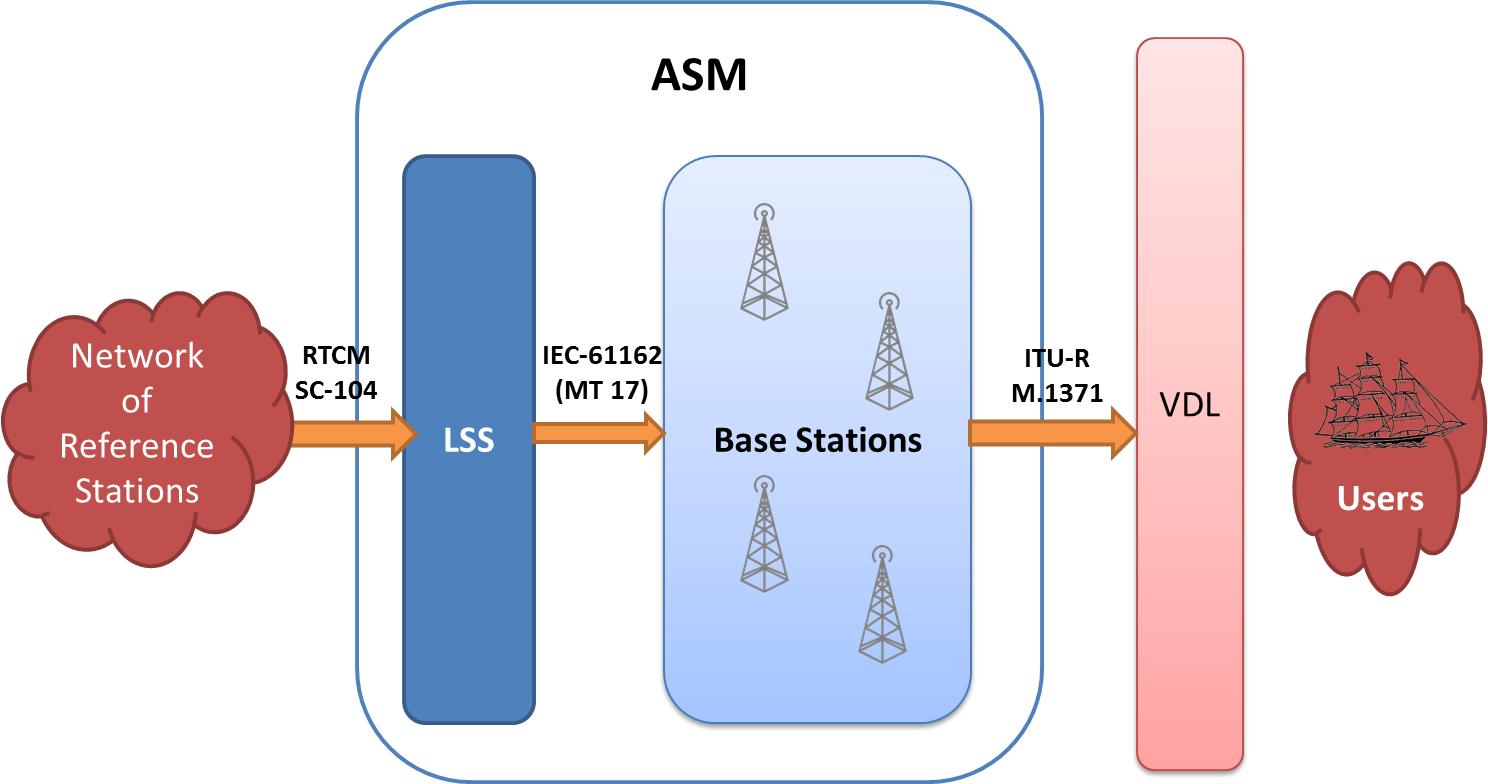
The corrections generated will be provided to the AIS Controller Unit in RTCM format (via the dedicated input port). Therefore, there will be no change with respect to the current interface, being the Controller Unit in charge of converting the RTCM message into VDL Message Type 17 format. As detailed 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 traditional reference station or converted from the SBAS message to RTCM format.

Finally, it is important to remark that the provision of DGNSS corrections is not a core functionality of the AIS system, just an optional message that could be transmitted through the Message Type (MT) 17. Therefore, the VDL channel monitoring does not depend on the transmission or not of this message. For that reason, for the design of the architectures (decentralised and centralised) presented in this paper, the monitoring of the VDL channel has not been taken into account.

#### EGNOS based DGNSS solution over Centralised AIS service

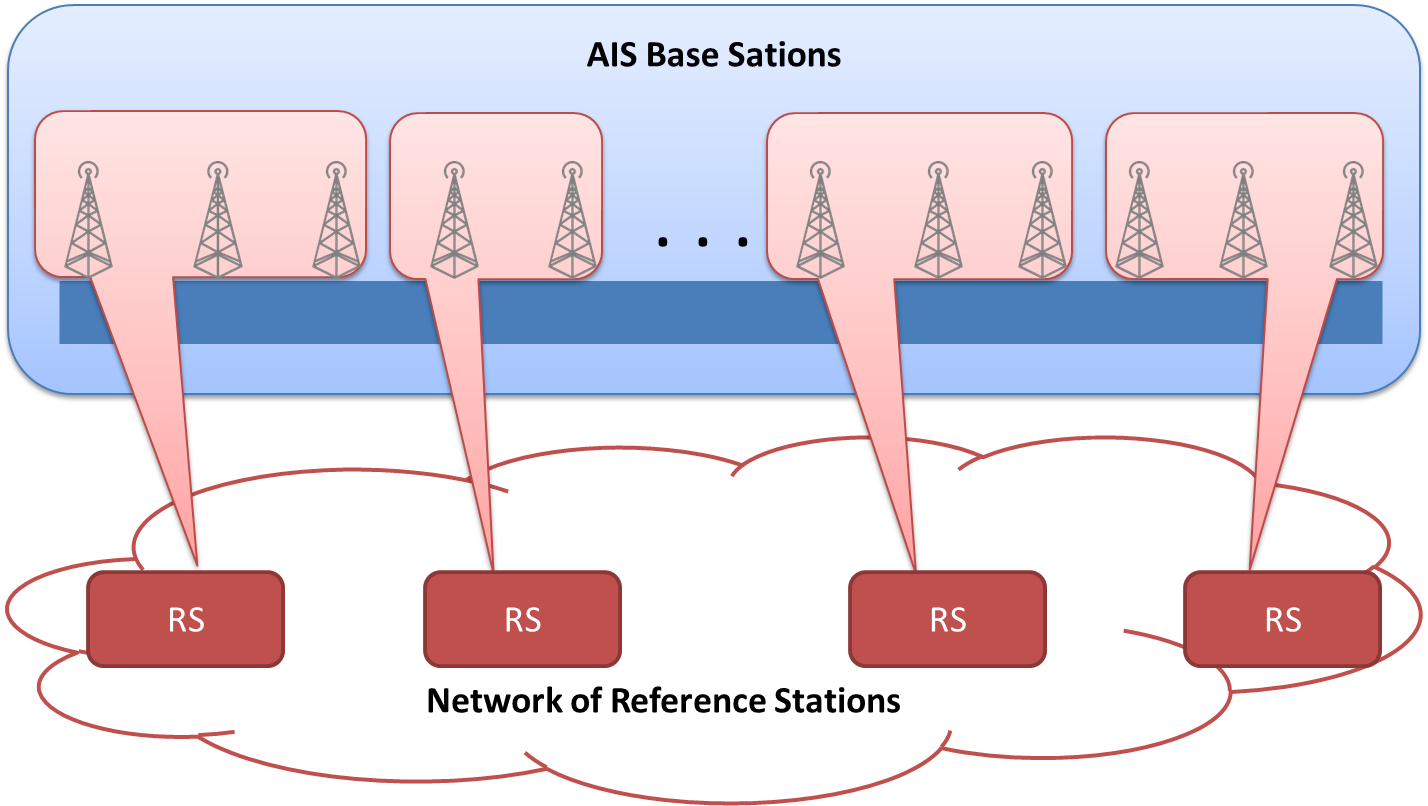
Although it is possible to generate the MT 17 in an ‘isolated’ base station, the most common solution for the provision of DGNSS corrections via AIS is to generate the Message Type 17 in a central facility (ASM) and distribute it to the different AIS base stations.

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 Message Type 17 generated by the Logical Shore Station is then provided to each base station and finally transmitted to the users through the VDL channel.



1. Traditional 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. This architecture is depicted in the following figure.



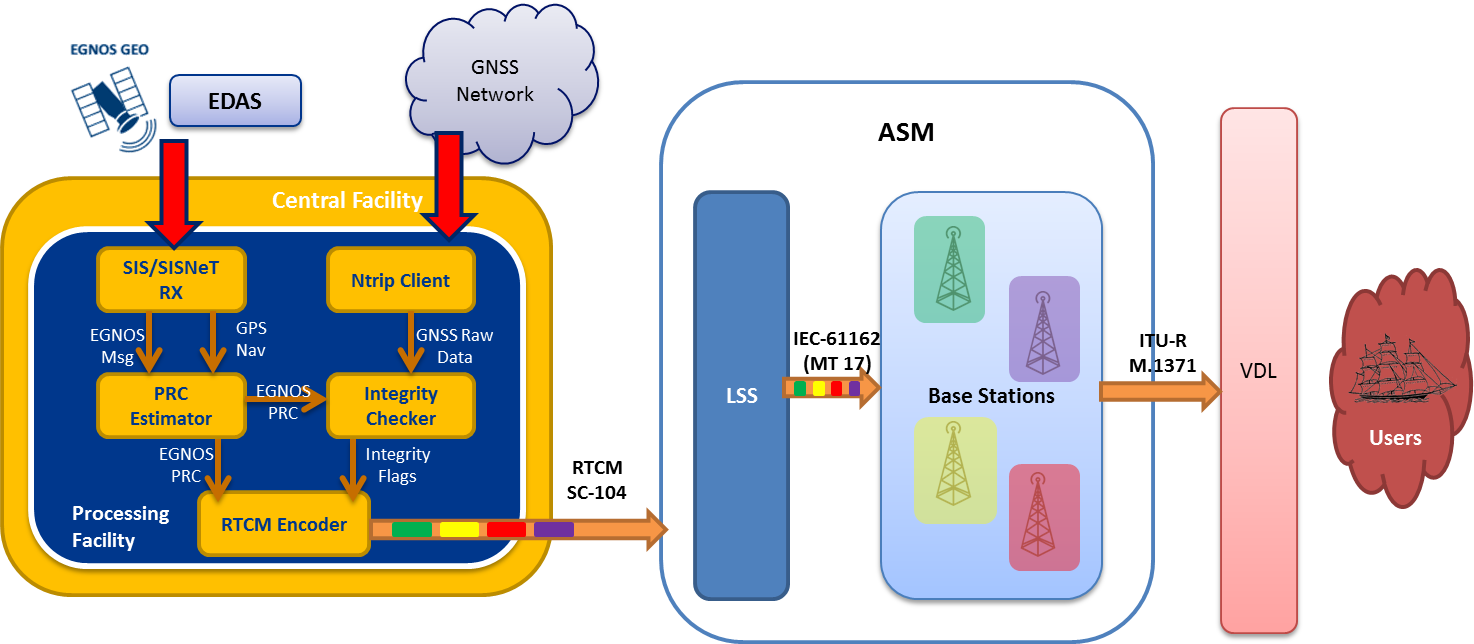
1. DGNSS over AIS Network Configuration

By contrast, the EGNOS corrections in RTCA format can be customized and converted into RTCM format for any location placed within the EGNOS 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 traditional 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 (ASM)**, which retrieves the EGNOS 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.



1. EGNOS 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 EGNOS 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 DGPS corrections to be broadcast by the transmitter could be the EGNOS Signal in Space or the EGNOS messages received from EDAS.

Also, in order to check the integrity of the corrections computed based on SBAS, the Central Facility processes the GPS raw data received from a network of GNSS receivers. This network could be a dedicated/proprietary one (set of receivers specifically deployed near the beacon transmitters) or take advantage of the GNSS networks available.

* Monitoring Network

As stated above, the Central Facility needs to have access to GPS 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 available. 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 (ASM)

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 (ASM 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 traditional DGNSS solution. All the inputs/outputs are the same and in the same format, therefore, no change is required. This means that the fact that the RTCM corrections are generated based on the EGNOS message or by a traditional DGNSS reference station is completely transparent for the ASM.

### SBAS over other data channels under development such as VDES (VHF Data Exchange System)

To be completed.

# CONSIDERATION ON HOW SBAS CAN BE USED IN A RESILIENT PNT SYSTEM

Body Text

# PRE-REQUISITE FOR THE ADOPTION OF SBAS

Body Text

# CONCLUSIONS

Body text

# ACRONYMS

AIS Automatic Identification System

ASM AIS Service Manager

AtoN Aid(s) to Navigation

ATU Antenna Training Unit

CF Central facility

CS Control Station

DGNSS Differential Global Navigation Satellite System

DGPS Differential Global Positioning System

EDAS EGNOS Data Access Service

EGNOS European Geostationary Navigation Overlay Service

GEO Geostationary Earth Orbit

GLONASS Globalnaya Navigatsionnaya Sputnikovaya Sistema

GNSS Global Navigation Satellite System

GPS Global Positioning System

HW Hardware

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities

IEC International Electrotechnical Commission

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)

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 Timin

PR Pseudorange

PRC Pseudorange Correction(s)

PSS 10.3.2 (AIS)

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)

VDL VHF Data Link

VRS Virtual Reference Station

WGS84 World Geodetic System 1984 (Reference coordinate system used by GPS)

# 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 2014
10. European GNSSS 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. EGNOS POTENTIAL ARCHITECTURES

This annex provides a list of potential architectures that could be used for the transmission of EGNOS corrections over existing Maritime AtoN (AIS or DGPS stations). These architectures have been considered for the trade-off analysis presented in Section 4.3.

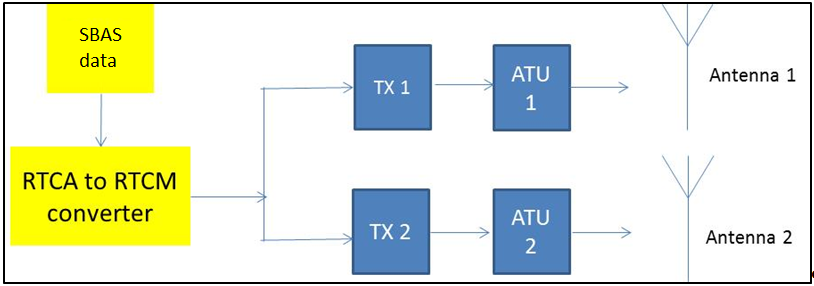
* 1. EGNOS OVER IALA BEACONS

To be completed

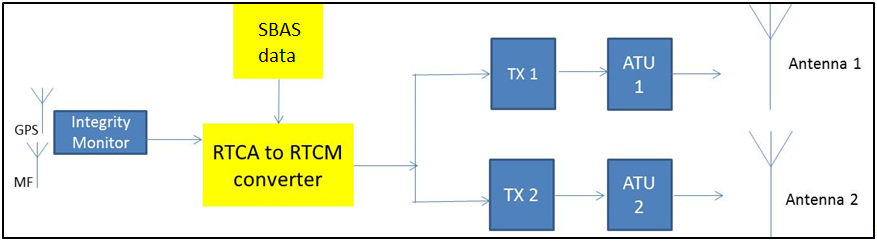
1. SBAS data extracted and converted to the form of maritime beacon correction information (RTCM format data)

Approach A considers the conversion of SBAS data (either from SiS or via Internet) for transmission on the marine beacon infrastructure, using the RTCM format and data content. A RTCA to RTCM converter is considered and would need to be able to provide the correct format and control the station health flags.

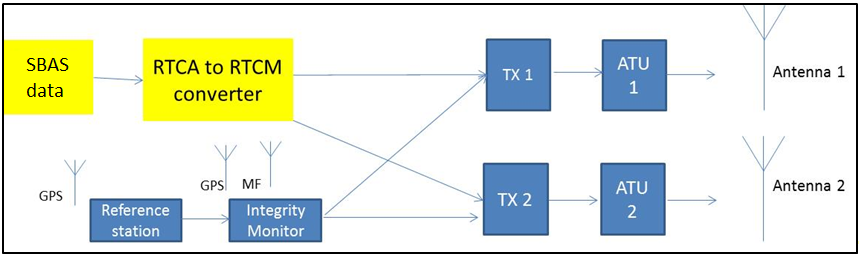
The Figures below outline three possible architectures which could be considered under Approach A.



1. Approach A with minimal infrastructure (referred as A.1)



1. Approach A with local integrity monitor (referred to as A.2)



1. Approach A with SBAS and marine beacon DGPS providing complementary services and back-up to each other (referred to A.3)

Approach A can be considered with three levels of complexity, each with its own set of pros and cons.

* Approach A.1 has the least amount of infrastructure but offers no local integrity monitoring or fall back should communications fail.

Therefore, it is most likely that the liability would need to reside with the SBAS Service provider and could lead to a more stringent Service Level Agreement (SLA). The ability to enforce such a SLA would also need to be considered reflecting the overall governance arrangements. There is likely to be a significant SLA in place with the communications provider as well.

It should be noted that in this case the signal broadcast will be labelled as unmonitored – not used by onboard receivers.

* Approach A.2 would include a local integrity monitor which would then inform the mariner if a fault condition was detected with either the broadcast signal or SBAS-derived correction data.

As the service will be used to help navigate vessels, this is a vital addition for such a safety of life service.

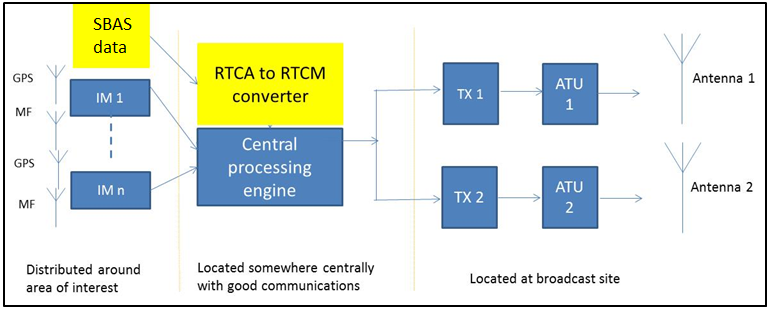
* Approach A.3 includes a local reference station at the broadcast site in addition to the integrity monitor.

The inclusion of the local reference station would allow for a complementary use of both systems, allow both sources to back each other up – therefore should either generation method fail the mariner will continue to receive the service. In addition, having two dissimilar means of generating corrections would allow the correction data to be compared as an additional integrity check. The technical implementation of this needs to be further analysed.

Either system identified in this approach can be the primary source of correction information; their order in the image does not imply priority. The A.3 Approach removes the reliance on communications, which should lead to greater availability for the service.

Note that alternative architectures for approach A.3 could be analysed: for instance, the architecture in Figure 15 could be simplified in one chain, where the Rx at the Reference Station is also SBAS-enabled and can do parallel processing.

Approach A would take the format as outlined in the figures below, for the distributed and hybrid architectures.

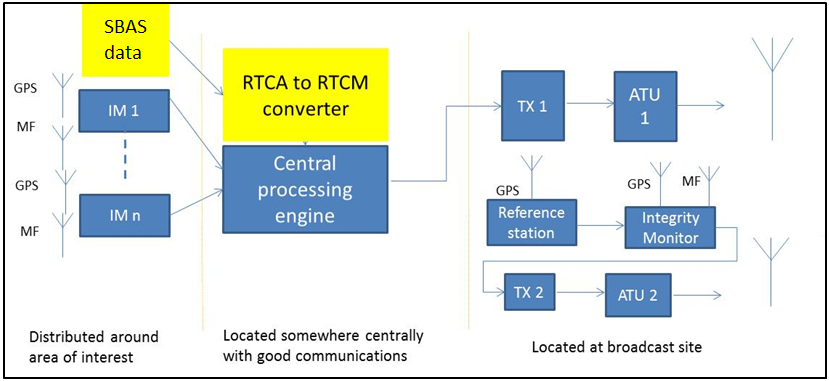


1. Approach A with SBAS data fed into the distributed approach (referred to as A.4)

* Approach A.4 would require SBAS data to be provided either via SiS or via an Internet to a central processing unit.

This unit would then decode the data, generate the model of the atmospheric delays and other errors associated encapsulated in the marine beacon information. The central processing engine would then need to generate the virtual reference station correction information, based on the location of the transmitter site (in RTCM format). These corrections are then sent over a communications medium to the broadcast site for transmission to the mariner. It is expected that an integrity monitor local to the broadcast site would be used to monitor the performance of the correction information and transmission link.

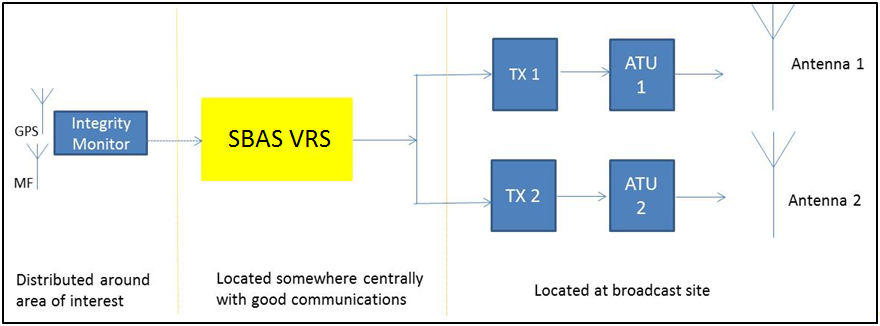
This approach would have the same reliance on communications as outlined previously, therefore the hybrid approach may be considered, as shown in Figure 16. This approach may be modified further by the inclusion of SBAS data sourced locally at the broadcast site for use in the on-site solution.



1. Approach A with SBAS data fed into the distributed approach with back up option (referred to as A.5)
2. SBAS Internet (EGNOS EDAS) virtual reference station data used in place of ‘central processing engine’ in distributed approach.

Approach B considers the use of a virtual reference station (VRS) solution provided, presumably, as part of the SBAS Data Access Service (EGNOS EDAS for the moment). Little public reference is available for this approach. Therefore, much of this section is based on a generic understanding of the concept and may need revision when more information is widely available.

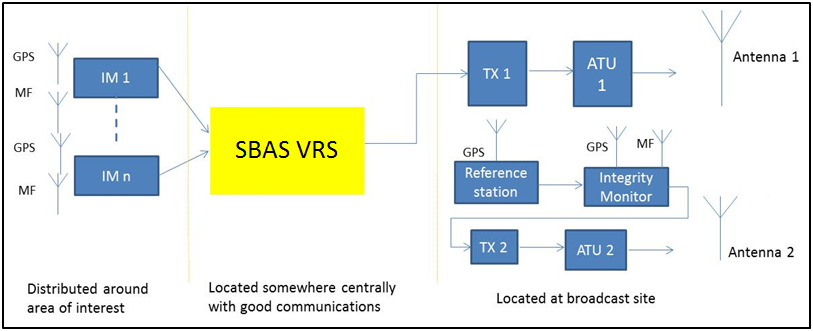
Given the virtual reference station nature of this EDAS service, it does not fit the local architecture approach and therefore this is not considered. The virtual reference station approach is most suited for use within the distributed and hybrid architectures; these are considered in Figure 18 and Figure 19 respectively.



1. Approach B considered with the distributed architecture

As shown in Figure 18, the SBAS VRS data replaces the previous central processing engine and generates correction data in the correct maritime data format, based on the transmitter location, which is then sent for broadcast via a 3rd party data link.

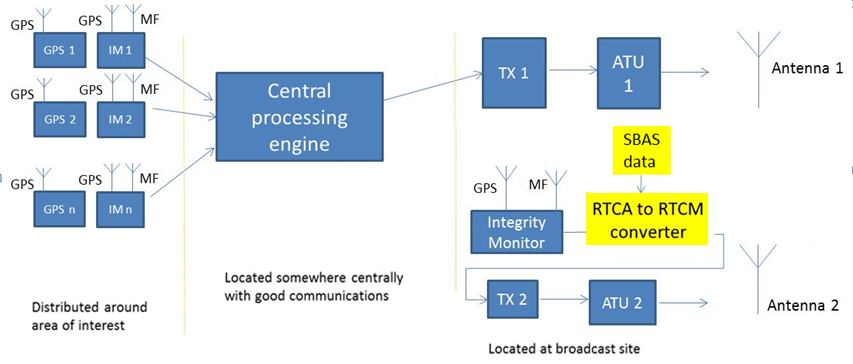
As with the other examples of this infrastructure, there remains a significant reliance on the communications link to the broadcast site. However, in this case there is also a reliance on the provision of data from SBAS Internet Service (EGNOS EDAS). While there are a number of possible methods of mitigating any outage, it is likely that a detailed SLA will be required.



1. Approach B considered with the hybrid architecture

As before, the hybrid approach may be considered with the provision of a local back up at the broadcast site. SBAS data, using off-air information, may be integrated into the local correction chain, although this is not shown in the diagram.

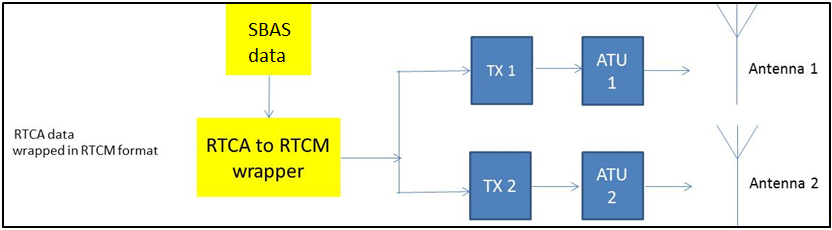
1. Approach C: SBAS information (from SiS) used to provide a local backup at the transmitting site when using the VRS approach to bridge network interruptions (similar to B but exchanging the roles of SBAS)



1. Approach C: SBAS information (from SiS) used to provide a local backup at the transmitting site when using the VRS approach
2. SBAS data repeated over the MF link (presented as is in RTCA format)

Figure 21 provides a generic schematic for the re-broadcast of SBAS SiS data (or Internet Data if available), provided in a RTCA format. Existing marine beacon receivers are designed to receive data in an RTCM format and there is no RTCM format capable of transmitting SBAS data, or RTCA formatted data.

In this scenario, SBAS data broadcast in the RTCA format is maintained but is sufficiently encased in the RTCM plain text message, which would enable it to be transmitted using existing infrastructure and enable existing receivers to decode the data. Legacy receivers would not know how to deal with the data in that format, therefore receiver updates would be required in order to then apply the SBAS RTCA data.



1. Generic schematic for SBAS data re-broadcast over marine beacon infrastructure at the local broadcast sit

Approach D has a number of issues:

* Data throughput may not be sufficiently high enough (latency of data and frequency of updates). Further investigation is needed;
* Legacy receivers will ignore the RTCA data. Receivers will need a firmware upgrade to make use of the data;
* The integrity monitoring of this approach should also be discussed.

While not shown, an integrity monitor may be required at the local site to ensure the integrity of the medium frequency transmission and the quality of the data (e.g. Bit Error Rate, but will not check the correction data, unless updated to do so).

SBAS information displaces the marine beacon information and therefore does not act as a complementary or back up system to marine beacon and vice versa. Without the in-depth study into the two systems this may be a significant risk.

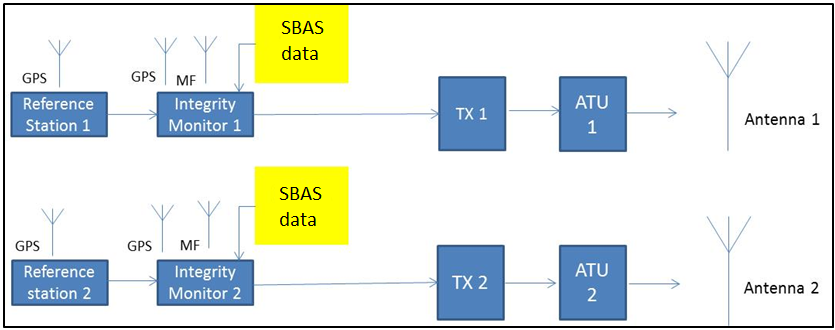
Approach A is unlikely to be considered with the distributed beacon architecture (and as such the hybrid architecture) as other approaches may be more appropriate. However, encapsulated RTCA data could be provided if deemed appropriate.

* 1. SBAS data used as an additional integrity check

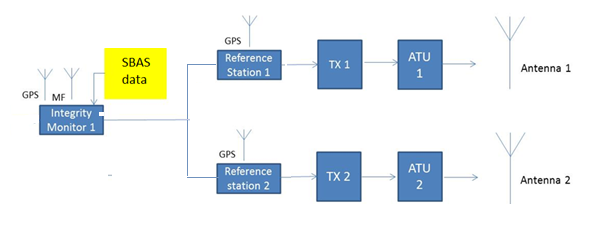
This case analyses the use of SBAS information as an additional integrity check on the existing beacon infrastructure (SBAS data not part of the transmitted information). SBAS data is used as an additional integrity check and does not propagate through to the mariner. In this case the transmission remains the same as that currently applied, based either in the Classic architecture or in the Network architecture, as described in IALA Guideline 1112.

As SBAS can provide an alternative position source, with integrity information, it can be used to corroborate the pseudorange corrections calculated on site by the local reference station and used within the integrity monitor. By comparing the marine beacon pseudorange correction information with that provided by SBAS, it should be possible to identify any significant differences, should the station be affected by external influences such as spoofing.

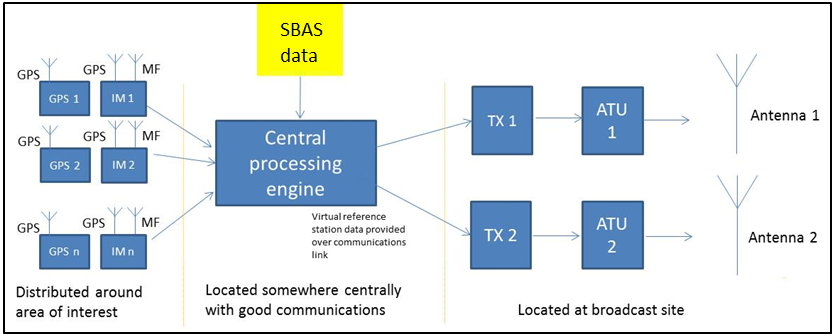
This data can be used within both the local and distributed architectures (classic and network approach), as shown below. Note SBAS data could be obtained either from SiS or Internet (EDAS).



1. SBAS used for an additional integrity check for a classic architecture



1. SBAS additional integrity check for another configuration of the classic architecture



1. SBAS data employed in the distributed architecture as an additional integrity check (Approach E, SBAS data either from SiS or Internet).
   1. EGNOS OVER AIS

To be completed

1. 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.

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. The accuracy is then limited by user receiver noise, inter-channel biases, user local effects and differential station location uncertainty.

EGNOS, as any SBAS system, is also providing corrections to the same errors (i.e. satellite clock and ephemeris errors and ionospheric delay estimation errors), with one exception: the troposphere. For this error source, SBAS systems do not provide corrections; users are expected to apply a model to reduce the error in the position due to this effect.

Taking this into account, the EGNOS messages can be used for the generation of Virtual Reference Stations (VRS). The principle behind this solution would be to convert the wide area EGNOS corrections in RTCA format, into local area corrections in RTCM SC-104 format (EGNOS-VRS) for the locations of interest for maritime users (e.g. beacon locations).

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

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

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

Where:

|  |  |
| --- | --- |
|  | is the RTCM MT1 PRC broadcast to the user |
|  | Is the most recent EGNOS fast corrections MT2-5 and 25 |
|  | Is the range rate corrections calculated according to equation A-17 in MOPS Appendix A using the most recent fast correction and a previous one. |
|  | Time of applicability of the most recent EGNOS fast correction |
|  | Reference time for the RTCM MT1 parameters |
|  | EGNOS clock correction from MT25 calculated according to MOPS Appendix A. |
|  | Speed of light 2.99792458x108 m/s |
|  | EGNOS 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 E-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. |
|  | Is the ionospheric delay calculated according to equation A-41 in MOPS Appendix A. Note this is always a negative value. |
|  | Is the tropospheric delay calculated according to section A.4.2.4 in MOPS Appendix A. Note this is always a negative value. |

The 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 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 EGNOS 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 EGNOS and also in view from the station. For the GPS satellites in view by the reference station and not-monitored by EGNOS, the E-DGNSS PRC shall be set to 1000 0000 0000 0000 and the E-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, EGNOS 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 take this EGNOS characteristic into account

* 1. 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 E-DGNSS RRC can be calculated using the difference between the last calculation of EGNOS PRC and a previous one available at the corrections processor. The approach proposed from [13] is basic and a first or second order filter would be possibly more appropriate, especially for the compensation of the residual ephemeris error discussed above .

Where:

|  |  |
| --- | --- |
|  | is the RTCM MT1 RRC broadcast to the user |
|  | Is the most recent E-DGNSS PRC calculated using the last set of EGNOS fast corrections available and its correspondent EGNOS slow corrections and, ionospheric corrections. |
|  | Is a previous E-DGNSS PRC calculated using a previous set of EGNOS fast corrections available and its correspondent EGNOS slow corrections and , ionospheric corrections. |
|  | Reference time for the RTCM MT1 parameters |
|  |  |

The calculation proposed is in line with MOPS229D. However, other approaches may yield better RRC performance. DGNSS receiver typically use a proprietary RRC algorithms based on a second order filter.

As the update rate of EGNOS fast corrections (typically six seconds) could be higher than the DGNSS MT1 update rate, note that the most recent E-DGNSS and a previous E-DGNSS PRC not necessarily are the last two E-DGNSS broadcast in MT1. The E-DGNSS PRC is a “snapshot” of the whole EGNOS 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 EGNOS messages update rate.

* 1. E-DGNSS UDRE

According to [5], DGNSS UDRE does not support integrity information(it is only used to weight the measurements to obtain a more accurate solution), 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.

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

Where

|  |  |
| --- | --- |
|  | E-DGNSS UDRE (squared) for an specific satellite at |
|  | Model variance for the long term, fast and range rate corrections as defined in MOPS Appendix A and J |
|  | Model variance for the slant range ionospheric error as defined in MOPS Appendix A and J. |
|  | 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.

* 1. E-DGNSS integrity alerts

EGNOS sends integrity flags for GPS satellites. EGNOS effective time to alert is 6 seconds. E-DGNSS must take advantage of the alert information broadcast by EGNOS. E-DGNSS might set a satellite as “Do not Use” (DU) immediately using RTCM MT1 or MT9, if EGNOS sets that satellite DU through EGNOS 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 E-DGNSS must send an alert for a satellite are:

* when either the E-DGNSS PRC or the RRC is higher than the maximum range for PRC (±10485.44m) or RRC (±4.064m/s) allowed by RTCM MT1.
* when EGNOS ionosphere corrections are not available for a satellite monitored by EGNOS.
  1. Summary E-DGNSS parameters

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

|  |  |
| --- | --- |
| **E-DGNSS Parameter for DGNSS MT1** | **Derived in** |
| UDRE |  |
| PRC |  |
| RRC |  |
| ISSUE OF DATA | Issue of data of the GPS navigation data being used. Also included in MT25 of MOPS Appendix A **[13]** |

1. Derivation of E\_DGNSS

1. The actual coverage area may vary slightly depending on the operation addressed, because it is directly linked to the target level of performance. [↑](#footnote-ref-1)
2. “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. [↑](#footnote-ref-2)