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Support to Maritime and Inland Waterways Service Providers for the Transmission of EGNOS Corrections via IALA Beacons and AIS/VDES Stations

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ABSTRACT: The use of SBAS corrections for navigation, in both coastal waters and inland waterways, has already brought the attention of many European authorities, which are interested in its potential to complement/replace their DGPS radio beacon networks.
The European GNSS Agency (GSA) has an active long-term trajectory working to foster the EGNOS adoption in maritime through the launch of several actions whose results will pave the way for the provision of maritime EGNOS services. In this line, GSA awarded the consortium ALG-Indra, ESSP and Alberding with the Specific Contract GSA/OP/07/13/SC24 'Support to Maritime Service Providers for the transmission of EGNOS corrections via IALA beacons and AIS/VDES stations'.
The main objective of this Specific Contract is to demonstrate the operational performance of the transmission of EGNOS corrections converted to Differential GPS corrections over the existing transmission infrastructure (AIS base stations/IALA beacons) in the Maritime and Inland Waterways (IWW) domains, while providing a detailed cost benefit analysis of the solutions proposed. This service may complement the current GNSS augmentation services exploiting synergies and benefiting from the current infrastructure and standards, facilitating the adoption of EGNOS by maritime and inland waterways authorities. Furthermore, the service has no impact at user level since the DGNSS corrections are transmitted over the existing infrastructure, in the same format and implementing the same integrity mechanisms required for traditional IALA beacons ([1]).
This project will allow the maritime and IWW service providers to have a clear understanding about the technical, operational and economic feasibility of the transmission of EGNOS corrections via IALA beacons and AIS/VDES stations.

1 INTRODUCTION

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's regional satellite-based augmentation system (SBAS). Today it improves the performance of GPS and from 2025 will augment Galileo as well. Since 2009 it is providing benefits in different maritime applications such as general navigation, especially in terms of increased accuracy.

EGNOS can provide multiple benefits to the maritime and IWW service providers. The most relevant ones are associated to three key features: free of charge access, redundancy of signal sources (Signal-in-Space (SiS) and EGNOS Data Access Service (EDAS)), and the possibility of making use of the **Virtual Reference Station (VRS)** concept. The main advantage of a DGPS solution based on VRS (using EGNOS messages as input, that is, EGNOS-based VRS) with respect to traditional DGPS is that corrections can be remotely generated for a specific location without the need of having a physical reference station at that location and ensure that the quality of the corrections is not affected by local errors (e.g. multipath/interference at transmitting site). Also, there are a number of EGNOS-based architectures that can be set-up to complement and/or replace traditional DGNSS networks, adapting to the specific operational scenario with a high degree of versatility.

The European GNSS Agency (GSA) is fostering the adoption of EGNOS V2 in maritime, with different active lines of action for general navigation. The current paper reports on the activities in the frame of Specific Contract GSA/OP/07/13/SC24, which aims at promoting the adoption of EGNOS in maritime by supporting service providers to implement and test the transmission of EGNOS corrections through existing national Administrations' infrastructure (IALA beacons and AIS/VDES stations). This will be achieved by demonstrating the operational performance of the transmission of EGNOS corrections converted to Differential GPS corrections over the existing transmission infrastructure in the Maritime and Inland Waterways (IWW) domains, while providing a detailed cost benefit analysis of the solutions proposed.

This service may complement the current GNSS augmentation services exploiting synergies and benefiting from the current infrastructure and standards. Furthermore, the service has no impact at user level since the DGNSS corrections are transmitted over the existing infrastructure, in the same format and implementing the same integrity mechanisms required for traditional IALA beacons (i.e. [2]).

2 PROJECT STRUCTURE

The organizations involved in the project team are: GSA (customer), ALG (prime contractor), Indra, ESSP, and Alberding GmbH (subcontractors). Additionally, several European maritime and inland waterways authorities are actively contributing to the project.

The project has been distributed in two phases:

– First phase – preliminary tests - (which lasted for 7 months and ended in April 2018) was aimed at verifying the feasibility of using EGNOS as a source for the Differential GNSS (DGNSS) corrections to be transmitted via IALA beacons and AIS/VDES stations. This was achieved by a set of preliminary tests performed without signal broadcast, but focused on the locations where pilot projects were implemented in the second phase of the project and with a configuration as close as possible to the operational one. Also, the same SW solution (provided by Alberding GmbH) to be used for the real tests –pilot projects- was used for the generation of the EGNOS-based DGPS corrections (conversion from RTCA to RTCM format) and the required integrity verifications, ensuring the representativeness of the preliminary tests. Due to the promising results of this phase, GSA authorized the Consortium to proceed to project phase 2 at the beginning of April 2018.
– Second phase – pilot projects - (lasting 10 months and ending in January 2019) was aimed at deploying and testing via four (4) pilot projects the EGNOS-based solutions in various European locations re-using as much as possible the currently available infrastructure. Cost Benefit Analysis were also developed and customized (with the support of the corresponding authorities) for the countries hosting a pilot project. Additionally, a liability analysis was performed in order to understand the regulatory constraints that may apply to the proposed solutions with the objective to achieve a harmonized approach to be followed by Maritime and Inland Waterways authorities.

A total of **seven (7) European Maritime and Inland Waterways** (IWW) authorities have contributed to the project, namely: CEREMA (France), GLA (United Kingdom and Ireland), Kystverket (Norway), MRCC (Latvia), Puertos del Estado (Spain), RSOE (Hungary), and WSV (Germany). Some of these authorities (**MRCC, Puertos del Estado, RSOE and WSV**) have also provided their infrastructure to **host a pilot project** to demonstrate the operational performance of the transmission of the EGNOS corrections. They have also supported the project by providing information to generate realistic cost benefit analysis and reviewing their outcomes afterwards.

The paper focuses on the results achieved during the second phase of the project, when real signal broadcast was used.

3 TECHNICAL FEASIBILITY ANALYSIS

Four (4) European scenarios have been analysed and the most suitable architectures to transmit the EGNOS-based VRS differential corrections have been selected, which can be either centralised or de-centralised. A fair combination of both IALA beacons and AIS/VDES stations as well as maritime and IWW domains have been chosen. The duration of the pilot projects has been **six (6) months**. Data has been collected from both static and dynamic receivers.

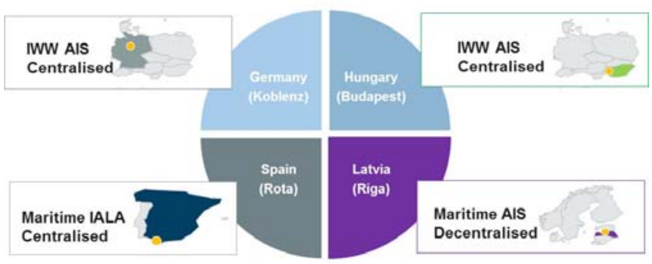

Figure 1. Pilot project locations and architectures/domains

4 EGNOS-BASED ARCHITECTURES IMPLEMENTED IN THE PILOT PROJECTS

From the recommended EGNOS-based architectures detailed in [1], the following have been implemented in the pilot projects:

Table 1. Pilot projects domains and architectures

Scenario	Domain	Architecture implemented
Rota	IALA maritime	Hybrid centralised
Koblenz	AIS inland	AIS centralised
Budapest	AIS inland	AIS centralised
Riga	AIS maritime	AIS decentralised – external source

4.1 *Hybrid centralized architecture (IALA beacon in Spain)*

This solution combines a classical DGNSS station deployed at each beacon site with a centralized EGNOS based VRS solution. For the EGNOS-based VRS solution (right chain in Figure 2), both the RS and the IM stations are centralized in the "Central Facility", and therefore, the only infrastructure needed at each beacon site is the communication lines and the transmission equipment. Additionally, a network of GNSS receivers is needed for the integrity check. At least one receiver located within the coverage range of each beacon transmitter and able to transmit the GNSS raw data collected to the central server shall be available.

On the other hand, it is noted that the network approach results in high requirements concerning the availability and quality of the communication links.

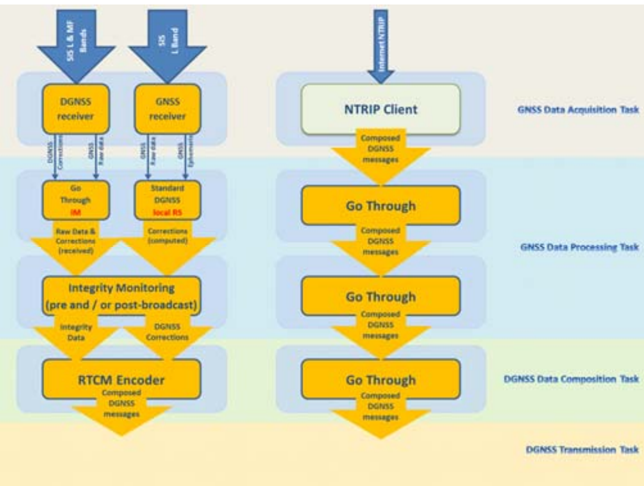

Figure 2. Hybrid Centralized Architecture: classical DGNSS + SBAS Based VRS (functional view)

As agreed with the Spanish Ports authority (PdE), one of the GNSS receivers in the classical DGNSS architecture (left chain in Figure 2) was also used to monitor the signal and corrections transmitted by the EGNOS based solution (right chain in Figure 2). Data collected by this receiver was sent to the central server for the integrity check.

4.2 *AIS decentralized architecture – external source (AIS station in Latvia)*

In those AIS Base Stations where there is no access (either via radio or serial connection) to the DGPS messages provided by a IALA beacon, the pseudorange corrections can be generated locally using the EGNOS message (either obtained from the EGNOS SIS or from the EDAS service).

DGNSS corrections are provided as input (via a dedicated portFigure 4) to the AIS Base Station, therefore, whether these corrections are received from a traditional DGNSS stations or generated based on EGNOS 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 just implementing an external component that converts the EGNOS wide area corrections in RTCA format into local area corrections in RTCM. 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.

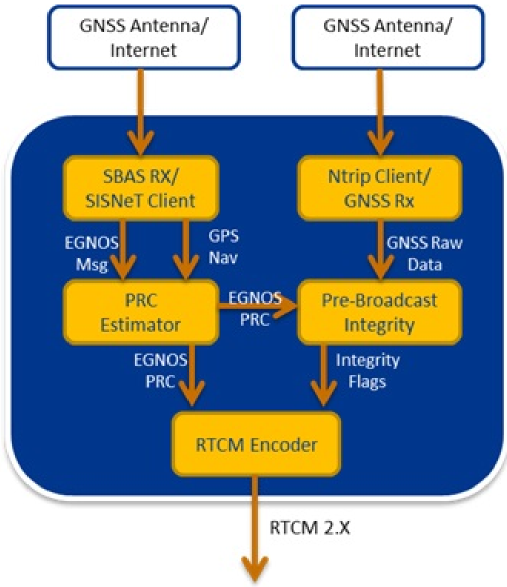

Figure 3. EGNOS-based AIS station: RS & IM block diagram

In the Riga pilot, an SBAS enabled receiver was used to obtain the EGNOS message. Hence, GNSS observations collected by this receiver were used to check the integrity of the data (note that the observations were not used to generate the differential corrections, and therefore, the same receiver can be used for the corrections generation and the integrity check).

The corrections generated by the RTCA to RTCM converter were provided to the AIS Controller Unit in Message Type 17 format (via the dedicated input port).

4.3 *AIS centralized architecture (AIS station in Germany and Hungary)*

This solution consists on generating the EGNOS-based VRS streams in a central facility. Through the AIS Service Manager (ASM), these corrections are then routed and sent to each AIS base station. At very high level, the architecture of this solution is depicted in the following diagram:

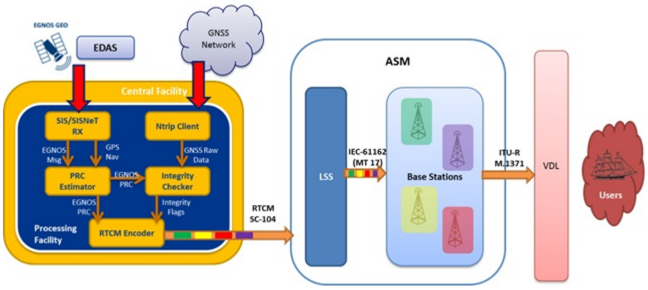

Figure 4. EGNOS-based AIS centralized architecture

- **Central Facility:** 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 SBAS Signal in Space or the SBAS messages received from EDAS.
- **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. Considering that the corrections are generated and integrity checked in the central server, the communication links and the protocol for the data transmission between the central server and the ASM shall be designed to ensure the **integrity** of the corrections provided. In case of using the NTRIP protocol for the data transmission, the TLS option could be selected to ensure communication privacy and data integrity.
  Internally to the AIS service each correction set will be routed to the target AIS Base Station (AIS-PCU) by the AIS-LSS.
- **Monitoring Network:** For the integrity monitoring check, 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. How this data is fed in the central facility would depend on each particular implementation. For instance, the NTRIP protocol designed to disseminate GNSS raw data and differential corrections over internet could be used to transmit the raw data from the receiver location to the central facility. In the case of the Koblenz and Budapest pilot projects, since a single monitoring receiver is used, standard TCP/IP connections are used.

4.4 *Performance assessment: definitions and assumptions*

- **Availability:** percentage of time EGNOS-based corrections are available to the user. This means that the following failures have not been included in this computation:
  - HW and SW failures related to pilot project setup and not representative of an operational set-up.
  - Malfunctions detected in the rover receiver.
- **Continuity:** Probability that a signal failure incident will start during the Continuity Time Interval (CTI).

$$Continuity = 1 - CTI/MTBF$$

where CTI is **15 minutes** as stated in [4] and MTBF is the Mean Time Between Failures measured over **two years**.
For the present analysis, a failure is considered an event when the EGNOS-based DGPS corrections are not available for the user (after being integrity-checked) and therefore, it is not possible to compute a differential solution.
- **Accuracy:** it is based only on the DGPS epochs using EGNOS-VRS corrections marked healthy (standalone epochs, "not-monitored" and "not-working" epochs are excluded from the accuracy statistics).
- **Integrity analysis:** integrity approach is based on the Pre-Broadcast Monitoring concept. Corrections are checked both in the pseudorange and position domains as already explained for the preliminary tests.

  This means that:
- EGNOS SiS/EDAS data gaps are taken into account for the availability and continuity results.
- Monitoring station data gaps are taken into account for the availability and continuity results.
- Transmission failures are taken into account for the availability and continuity results.
- User receiver data gaps are NOT taken into account for the availability and continuity results.

4.5 *Minimum user requirements*

In order to assess the compliance with the minimum maritime user requirements for coastal and inland waterways navigation defined by IMO [4], a detailed analysis of the accuracy, availability, continuity and integrity performance has been performed for each pilot project. According to [3], the following table summarises the requirements specified in [4], augmented by those described in [5]:

	System Level				Service Level	
	Absolute Horizontal Accuracy (95%)	Integrity			Availability (2 years)	Continuity (over 15 minutes)
		Alarm Limit	Time to Alarm[1]	Integrity Risk		
Area	m	m	s	%	%	%
Ocean	≤ 100	N/A	N/A	N/A	≥ 99.8	N/A
Harbour entrances, harbour approaches and coastal waters	≤ 10	25	10	10^{-5}	≥ 99.8	99.97

[1] *Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities;*

Figure 5. Maritime requirements based on IMO Recommendations

Based on the above maritime requirements specified by IMO and IALA, European inland waterway navigation experts defined the following set of requirements in the framework of the IRIS Europe II project [6]:

- Horizontal Accuracy (95%): 3 m
- Availability (per 30 days): 99.8 %
- Continuity (over 15 minutes): 99.97 %
- Integrity Time to Alarm: 10 s

Although more stringent in terms of accuracy, these requirements are deemed to be suitable for inland waterways by the experts and therefore have been taken into account in the current report.

Furthermore, according to [7]1, the continuity of each individual reference station shall be >99.95% in case the DGNSS service consist of areas of overlapping coverage. Due to the relatively flat terrain of Hungary and the dense network of AIS Base Stations deployed along the Hungarian stretch of the river Danube, the VHF signal of multiple AIS Base Stations can be received at any location on the river, including the capital Budapest. Therefore the continuity minimum requirement of >99.95% has been applied in this pilot project.

4.6 *Performance results*

The following table summarizes the results obtained during the test campaign:

Table 2. Pilot projects performance results

Pilot Project	Availability	Continuity	Accuracy (95%, m)	Integrity
HU (RSOE, Budapest)	99.98 %	99.95 %	2.05 m	Pseudorange domain: several high PRC residual error events affecting individual low-elevation satellites only Position domain: 2 major events (both not-monitored) taking several minutes each and 7 short events (most of them not-monitored and a few no data) ranging from a few seconds to a few minutes
DE (WSV, Koblenz)	99.99 %	98.95 %	1.11 m	Pseudorange domain: several high PRC residual error events affecting individual low-elevation satellites only. Position domain: Lots of short events (unmonitored).
LV (MRCC, Riga)	99.83 %	98.98 %	3.60 m	Pseudorange domain: No events. Position domain: Some short events (unmonitored).
ES (PdE, Rota)	99.97%	99.38%	0.65 m	No integrity events detected.

4.7 *Budapest pilot project results*

This pilot project has run smoothly and results have met all the requirements set for inland navigation. The availability and continuity performance were impacted by two regional EGNOS performance degradation events occurred on the 20th of October (which lasted for about 27 minutes) and the 11th of November (which lasted for approximately 11 minutes). These performance degradation events only affected the south-east part of Europe. Accuracy results could have been improved if a higher quality FFM receiver with a geodetic antenna had been used in the test.

On the other hand, during the pilot project RSOE started transmitting differential corrections from other AIS Base Stations that follow the classical approach. This caused the transponder to swap from non-EGNOS based corrections to EGNOS-based corrections back and forth. Unfortunately, the transponder had problems when receiving the two sets of corrections and kept going to standalone mode even though corrections are being transmitted from at least one of the two locations. A firmware upgrade recommended by the manufacturer could not be fulfilled.

4.8 *Koblenz pilot project results*

Various installation/setup issues not related with EGNOS were solved at the beginning of the pilot project and from there onwards the pilot has run smoothly. The service continuity does not meet the requirement due to frequent continuity events caused by monitoring station data gaps and therefore not related with the EGNOS-based corrections themselves, but to the fact that the connection between the monitoring station and the central server is a simple DSL line.

It is noted that both the service level availability and the system level accuracy results obtained during the reporting period met the corresponding requirements for inland navigation.

4.9 *Riga pilot project results*

Due to some disturbances in the area, there were occasions when the rover transponder did not receive corrections in time. The reason for these transmission failures is not fully clear, but it affects the VHF signal availability.

It is noted that both the service level availability and the system level accuracy results obtained during the reporting period met the corresponding requirements for maritime navigation. Accuracy values are slightly worse than in other pilot projects, probably due to local interferences. It is suspected that rover in Dzirnezers (used as Far Field Monitor) is affected by multipath since it is installed in a metal tower. In any case, these values could have been improved if a higher quality FFM receiver with a geodetic antenna had been used in the test.

The continuity requirement could not be met. Continuity events were caused by monitoring station data gaps (LAN communication issues) or configuration changes (SW restarts), and therefore, not related with the EGNOS-based corrections themselves.

4.10 *Rota pilot project results*

Several issues with the installation, failures on the transmitter (allegedly due to drops in the line voltage) and problems with the rover receiver led to the situation where no clean statistics could be derived for the first period of analysis (from June to beginning of October). In October 2018, the former receiver and the antenna were replaced by a Trimble SPS351 DGPS/Beacon receiver and the GA530 antenna. Also, the communication line in Rota was updated to optical fibre technology.

The new performance analysis is remarkable for the excellent accuracy results obtained with the newly installed Trimble receiver (horizontal error at the 95 percentile clear below 1 meter) and also for the high availability of the EGNOS-based corrections computed at the central server. The continuity computed at the Rota DGPS (service continuity) was 99.38%.

The two main issues affecting system availability and system continuity (at the FFM receiver) are the following:

- **Monitoring data delay:** On certain epochs, the GNSS measurements collected by the Rota receiver and used for the integrity check are received in the central server with a delay greater than 5 seconds. This makes the Alberding SW discard these measurements and therefore, consider the PRC corrections as not-monitored, with the corresponding impact on the availability and continuity performance.
- **Obsolete corrections broadcasting:** In case of communications data gap, the corrections generated at the central server are received all at once at the beacon site. This information goes from the Euronet SW in the embedded PC to the MSK modulator for its final transmission to the users via radio. During this whole chain, the timestamp of the corrections is not checked, and therefore, the obsolete corrections that were buffered during the network failure are transmitted to the users. Considering the low throughput of the radio transmission, it takes several hours till the whole buffered data is transmitted and the current corrections are actually broadcasted.

4.11 *Pilot projects results summary*

Green cells indicate that the performance is compliant with IMO requirements, whereas red cells indicate the opposite. Based on these results shown above, it is concluded that the **availability** of the EGNOS-based corrections is enough to meet the 99.8% availability requirement defined by IMO in the A.915 [5] and A.1046 [4] resolutions.

As it can be derived from the table, the most demanding performance parameter is the **service continuity**. The reason why there are red cells in the table above is due to missing monitoring raw data to perform the Pre-Broadcast Monitoring (PBM) check. The missing raw data causes short continuity events that have an impact on the parameter calculation. These raw data gaps/delays are due to the fact that pilot projects use conventional communication lines (i.e. not dedicated) to transmit data from the monitoring receiver to the central facility.

Regarding the **accuracy** results, it is to be noted that the position accuracy highly depends on the quality of the antenna and the GNSS receiver. In this sense, the results obtained for the Rota pilot project, where a high quality antenna and GPS receiver was used, illustrates the performance levels that could be obtained with an EGNOS-based solution (horizontal position error below 1 meters at the 95 percentile).

Finally, the results yield by the **integrity** monitoring module show that no single satellite correction has been discarded due to high PRC, RRC and only a few due to high corresponding residual values (affecting satellites at low elevations). This provides a quantitative measurement of the corrections quality. If the corrections are accurate, the differences between the geometric and the corrected pseudorange will be low and therefore good position accuracies will be obtained. At the position domain, only a few events with errors exceeding the horizontal position threshold have been detected in the Riga pilot project.

In summary, for all cases where adequate data was available and statistics could be computed, EGNOS-based corrections have proved to achieve performance levels above or closely below the requirements set by the IMO. This is mainly due to:

- the high availability of the EGNOS SiS (100% in the period of analysis when using combined SiS), and EDAS (only minor outages detected), and
- the high quality of the corrections generated.

5 COST BENEFIT ANALYSIS

The goal of the CBA is to translate the proposed technical architecture (DGNSS and EGNOS-based) of all the considered scenarios into an effective evaluation of costs and benefits. With this aim in mind, a five-step methodology has been developed:

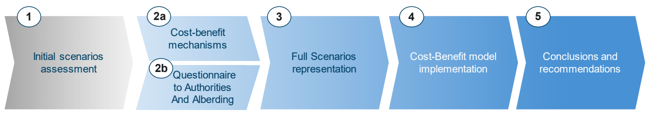

Figure 6. CBA methodology

The CBA builds upon a comparison (or Delta) of costs and benefits between a reference scenario, using traditional DGNSS infrastructure, and an EGNOS-based scenario. These costs and benefits are mainly originated by the difference in CAPEX and OPEX between reference and EGNOS scenario, deriving from different infrastructure deployment and maintenance requirements.

In close cooperation with the participating authorities, the consortium has developed a complete cost-benefit model that allows to quantify potential savings brought by EGNOS introduction in all the scenarios and to assess the optimal deployment strategy for maximising benefits of this transition. More specifically, for all the scenarios analysed the results have been the following:

Table 3. Phase 2 CBA results

Port Authority/ State	Domain	Reference Scenario Architecture	EGNOS Option Architecture	Total Savings	Savings percentage (EGNOS Option vs Reference Scenario)
MRCC/Latvia	Maritime	AIS decentralised	AIS centralised	0,19 Mln Eur	52%
Puertos del Estado/ Spain	Maritime	IALA decentralised	IALA centralised	1,8 Mln Eur (Hybrid Centralised)	28%
RSOE/Hungary	IWW	AIS centralised	AIS centralised	0,80 Mln Eur	19%
WSV/Germany	IWW	AIS centralised	AIS centralised	0,36 Mln Eur	5%

In Latvia, EGNOS could bring considerable added value in the transmission of corrections over the AIS Network; through centralisation, the EGNOS-based centralised option allows a notable amount of savings in comparison to the Reference Scenario. This happens since the CAPEX and OPEX for the central server and IM Stations in the EGNOS option are lower than the purchase costs of the required beacon stations to generate corrections in the reference scenario (no IALA beacons are available in Latvia).

EGNOS could also provide benefits to the rationalisation and modernisation of the IALA Network in Spain. The adoption of EGNOS allows benefits both in CAPEX and in OPEX. This happens since the setup costs for the central server and the purchase costs of IM stations in the EGNOS option are lower than the purchase costs of redundant traditional IALA beacons in the reference scenario, even taking into account that the proposed EGNOS based options are not fully centralised and maintain some decentralised components (especially for remote broadcast sites where reliable communications may not be available).

In Hungary, EGNOS could provide considerable benefits in the transmission of corrections over the AIS Network. Specifically, the CAPEX and OPEX for the central server and the additional IM Stations needed in the EGNOS option are lower than the purchase costs of DRS and IMS in the reference scenario. Besides cost advantages, the EGNOS solution foresees the generation of more localized sets of corrections for the AIS Base Stations (one set for a group of 3 stations with EGNOS versus one set for a group of 5 stations with DGNSS), providing additional operational benefits (performance improvement).

Finally, in Germany, the introduction of EGNOS could provide some benefits as well, since the purchase costs of IM Stations in the EGNOS option are lower than the purchase costs of RS in the reference scenario. It should be noted that in this case economic benefits are more limited. This is mainly due to the fact that the primary German system is already based on centralised approach (not EGNOS based), being already quite optimized from a cost/infrastructure point of view. In this case, the inclusion of EGNOS is expected to bring significant benefits in terms of robustness/redundancy.

6 OPERATIONAL BENEFITS

The project has also identified some operational benefits obtained when a centralized EGNOS-based solution is implemented, namely:

- **Reduction of spares and maintenance effort**: The rationalization of the infrastructure permits to rely on a more agile and lighter architecture, consisting on a smaller number of devices and tools, also for maintenance purposes. In return, this derives on a reduced number of man-days effort required to perform the maintenance activities.
- **Increased infrastructure robustness against RF interferences (jamming/spoofing):** In an EGNOS-based centralized architecture Reference Stations (RS) do not exist and hence, they cannot be jammed or spoofed. Only Integrity Monitoring Stations (IMS) can suffer this attack, which can be minimized by adding redundant IMS. In traditional DGNSS systems, however, since normally both RS and IMS are co-located, they can be equally jammed/spoofed.
- **Increased infrastructure robustness against failures:** When EGNOS is used in combination with traditional DGNSS (hybrid solution), EGNOS introduces redundancy on the source of the corrections. Furthermore, EGNOS corrections can be obtained via a double source: SiS or EDAS. This implies that, when a source of corrections fails, the system can automatically switch to a different source to avoid service interruption. Thus, the system is more robust to potential malfunctions coming either from: HW failures, SW failures and communication lines failures.
- **Synergies between IALA and AIS systems:** A centralised EGNOS solution could increase synergies between IALA and AIS systems, since the central server could generate corrections for both systems in an efficient way thanks to the VRS concept. These synergies could in return decrease the costs of generating corrections to be broadcasted by both systems.
- **Enhanced integrity at system level:** EGNOS corrections contain **integrity alerts** either in the Integrity Information Message (MT6) or the Fast Corrections Messages (MT2 to MT5 and MT24). The application SW will map these integrity alerts into **DGNSS RTCM format** for transmission by either setting the DGNSS MT1/9 PRC field to binary 1000 0000 0000 0000 (which means this satellite cannot be used for the navigation solution) or even, when the alert condition affects all satellites, by setting the Station Health field to "not working". On top of the EGNOS integrity check, the DGNSS system will continue providing alerts also at integrity monitoring level, as they currently do.

7 PROJECT RECOMMENDATIONS

A set of **recommendations** have been derived from the project, both for the **National Competent Authorities** (NCA) interested in implementing a similar solution as well as for the **GSA**. Some of these recommendations are as follows:

1 On the grounds of the outcomes of this project, NCAs are invited to carry out custom-built technical and Cost Benefit Analysis to evaluate the feasibility and benefits of using an EGNOS-based solution. The analysis should be particularized to their existing infrastructure, the typography of their country as well as the EGNOS coverage area.
2 GSA should try to push investigation of some outstanding issues at IALA level related to AIS, such as cross-borders coordination between countries and the fact that there is no body at European/International level to control the time slots used by AIS.
3 GSA should contribute to the generation of a full-European model to provide AtoN services based on EGNOS, perhaps through the development of more pilot projects to gain further understanding of the benefits of EGNOS at country level.
4 GSA should also continue supporting the investigation on the transmission of EGNOS-based corrections through VDES.

8 CONCLUSIONS

The project has demonstrated that EGNOS corrections, when retransmitted by existing IALA beacons and/or AIS Base Stations, perform in a very similar way as traditional DGNSS solutions and can yield important savings to authorities due to a rationalization of the infrastructure required at the transmitter sites.

This kind of solution also presents benefits, such as increased infrastructure robustness (against jamming and spoofing events and infrastructure failures), reduction of maintenance costs and an enhanced user integrity at system level.

In order to avoid gaps in the monitoring raw data due to communication problems, it is recommended to increase redundancy in the communication means by either (a) relying on a network of monitoring stations in the service area, and/or (b) diversifying the data links. This is the reason why it is highly advisable to make use of already available public GNSS data networks to minimise costs when adding this redundancy.

The results of the project have increased the EGNOS awareness among the maritime and the IWW communities, and are expected to act as a catalyst for the adoption of EGNOS in other sites and countries.

ACKNOWLEDGMENTS

The authors would like to acknowledge the European GNSS Agency (GSA) for their initiatives and efforts to analyze the potential of EDAS/EGNOS SiS to support the maritime community as a promising alternative for maritime navigation infrastructure modernization and rationalization.
The authors would also like to thank the seven European authorities involved in the project for their contributions and for giving us the possibility of using part of their infrastructure to deploy a pilot project.

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