GNSS evolution for maritime an incremental approach

Marco Porretta, David Jimenez Banos, Massimo Crisci, Giorgio Solari , Alessandra Fiumara

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Outline

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- GNSS for maritime: the current status.
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    - SoL applications
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INTRODUCTION

- Rising trends of marine accidents both in terms of number and cost are mainly associated with collisions and grounding

- In order to improve safety of navigation, IMO is promoting the « e-navigation » concept

- Several technological enablers are identified for the concept. These include amongst other:
    - an on board resilient multisystem PNT receiver . This receiver requires three complementary components:a core GNSS, an augmentation system, an adequate backup in the event of a GNSS system failure

INTRODUCTION: ESA activities and findings

- Activities:
  - Analysis of SoL mission requirements for maritime services:
    - What will be the requirements evolution?
    - What is a possible mapping of GNSS technologies to user requirements and operational concept?
  - Analysis of standardisation and certification processes:
  - Comparison of SBAS performance vs maritime requirements
  - Identification of both mid and long term objectives for the development of a suitable roadmap for GNSS-based maritime SoL services.

MARITIME NAVIGATION PERFORMANCE REQUIRMENTS

- Requirements for maritime navigation performance are indicated in two IMO resolutions.
- IMO 1046(27) deals with the requirements of a "Worldwide Radio Navigation System" (WWRNS). This includes GNSS, together with possible augmentation systems (e.g. DGNSS or SBAS), and other radio navigation systems such as eLoran.
  - WWRNS requirements are focused on the system performance (e.g. signal and system availability). Actual performance at the user level does not seem to be considered.
- IMO 915(22) specifies requirements for a future GNSS.
  - Requirements are expressed using the same RNPs used for aviation applications. Therefore, they are based on the actual performance at the user level.
  - From discussion with the maritime this requirement needs to be better consolidated

MARITIME NAVIGATION PERFORMANCE REQUIRMENTS WWRNS Requirements – IMO 1046(27)

- Two navigation phases are identified: (a) Ocean waters and (b) Harbour entrance, harbour approaches and coastal waters.
  - Accuracy: 100m and 10m (95%) for both phases.
  - Integrity: *"An integrity warning of system malfunction, non-availability or discontinuity should be provided to users" "as soon as practicable by Maritime Safety Information (MSI) systems"* (phase a) or *"within 10s"* (phase b). No specification is given about the relevant AL or the IR.
  - Availability: Signal availability should exceed 99.8% in both phases (No requirements for system availability).
  - Continuity: *"The system shall be considered available when it provides the required integrity for the given accuracy level. When the system is available, the service continuity should be ≥99.97% over a period of 15 minutes"* (phase b) only).

MARITIME NAVIGATION PERFORMANCE REQUIRMENTS
Future GNSS requirements – IMO 915(22)

- Same parameters adopted for aviation, based on actual performance at user level
- Lack of integrity concept, including key elements such as operational scenarios, environment description and consolidated standards.

Table of the minimum maritime user requirements for general navigation

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[2] (seconds)
	Horizontal (metres)	Alert limit (metres)	Time to alarm[2] (seconds)	Integrity risk (per 3 hours)				
Ocean	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: 1: Continuity is not relevant to ocean and coastal navigation.
2: More stringent requirements may be necessary for ships operating above 30 knots.

MARITIME NAVIGATION PERFORMANCE REQUIRMENTS
Integrity at the user level

— IMO 915(22) calls for integrity at the user level.

- This integrity concept requires the user to estimate, at each epoch, a maximum error bound (PLs) for the NSE.
- The assessment normally uses system integrity information and suitable models for the effects due to the local sources of errors (e.g. multipath, interference, shadowing or other propagation phenomena).
- PLs calculation can be either completely autonomous (e.g. RAIM) or based on additional information provided by the system (e.g. EGNOS V2 for aviation application).
- The more conservative the PL estimation, the larger the possible performance degradation in terms of availability and continuity.

GNSS for maritime: current status

— Only GPS and GLONASS are presently recognised as part of the WWRNS (IMO 915(22)) for ocean phase of navigation. For harbour entrance harbour entrance and coastal navigation, performance requirements are met with augmentation systems.

— Beidou recognised as a WWRNS in November 2014 (MSC-Circ 329)

— The application process for the recognition of Galileo as a part of the WWRNS was initiated by EC and is currently ongoing.

GNSS for maritime: DGNSS

- DGNSS is the most used GNSS solution for maritime applications.
- DGNSS provides the user with differential corrections (improved accuracy) and integrity information.
- Differential corrections are evaluated at a RS, which is placed at a known location.
- The "nominal" accuracy is between 3m and 5m. The larger the distance between the user and the RS, the larger the expected accuracy degradation (0.67m per 100km from the RS, according to IALA R-121).

GNSS for maritime
The DGNSS integrity concept

- The DGNSS integrity concept is based on the assessment of the quality of corrections. This is done at a separate DGNSS receiver (IM) which is placed at a known location, normally few hundred meters from the RS to avoid possible correlations for multipath events.
- At the IM, the quality of corrections is evaluated in both the position and the pseudo-range domains.
    - If pseudo-range or a position alarm is generated, the user will be promptly warned: a "do not use that SV" or "do not use the system" flag, respectively, will be included in the DGNSS message.
- The rationale underlying such integrity concept is that the IM receiver will experience the same level of performance of each user in the RS coverage area.

- The DGNSS integrity concept is not able to protect the user from possible local sources of errors (*). In IMCA 2011, an autonomous method (RAIM) to check, at the user receiver, the quality of GNSS position fixes is recommended.

GNSS for maritime
The current role of DGNSS

- As the DGNSS is not yet accepted as a part of the WWRNS, there is no specific maritime operation for which the use of DGNSS, as a primary means of navigation, is mandatory.
    - Although the majority of vessels are equipped with a DGNSS receiver, the final decision (and responsibility) for the navigation system to be used in a particular operation lies with the vessel captain.
- Log files produced by a certified DGNSS receiver can be used as evidence in legal controversial (source: IALA).
    - This requires that the receiver was installed, tested and operated in accordance with IEC 61108-4 standards.
    - No specific role is foreseen for RTCM. RTCM created the protocol for DGNSS that was mostly adopted by IEC. However, the mandatory standards are the IEC not the RTCM.

GNSS for maritime
WHAT ABOUT SBAS?

- SBAS are designed to support wide area (or regional) augmentation through the use of additional, satellite-broadcast, messages ("SBAS messages"). These systems are based on a network of ground monitoring stations, which are located at accurately surveyed points and monitor the signals of GNSS satellites. The measurements are collected and processed at a central facility where the SBAS messages are created.

- These messages include:
    a. Differential corrections; and
    b. The associated quality indicators (integrity at system level);

- The SBAS messages are then uplinked to one or more satellites (e.g. geostationary, GEO, satellites) and finally broadcasted to the end-users in the SBAS coverage area.

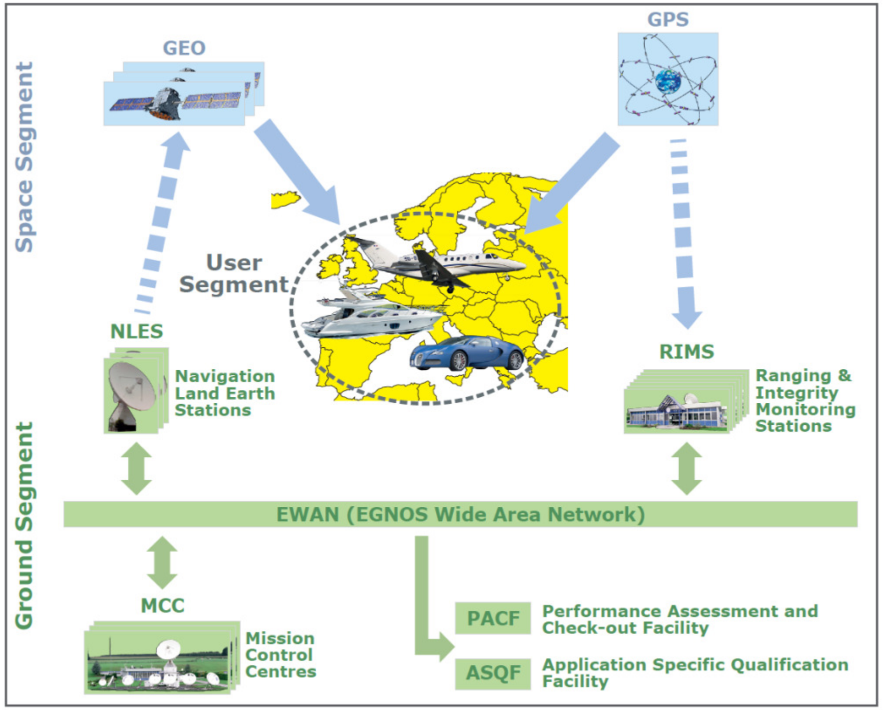
GNSS for maritime
WHAT ABOUT SBAS?
GNSS SoL Applications

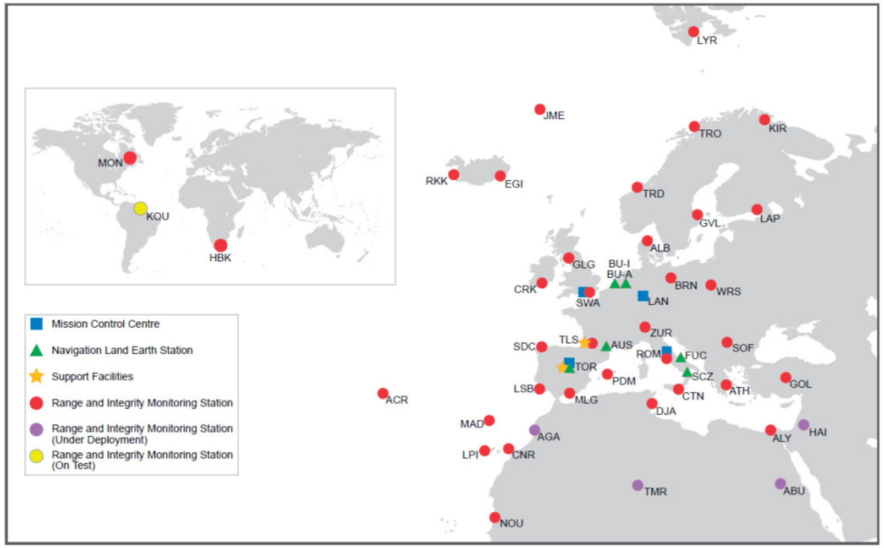
- SBAS is the incumbent GNSS solutions for SoL civil aviation applications.
- These systems are designed to increase accuracy and provide integrity.
- Accuracy is increased through differential corrections.
- Integrity is provided by enabling the user receiver to calculate suitable PLs. These are shown to effectively bound the maximum PE which is expected at the user level. Their calculation is based on:
  - The geometry of the satellites actually tracked by the receiver;
  - The (estimated) residual errors after the applications of the corrections; and
  - The (estimated) error contributions due to local sources of errors (e.g. multipath and receiver noise).

GNSS for maritime
WHAT ABOUT SBAS?
GNSS SoL Applications

- An integrity concept based on PL calculation requires the definition and the consolidation of a number of aspects, e.g.:
  - The acceptable Integrity Risk:
    - Risk apportionment amongst the different subsystems;
  - The operation duration:
    - Identification of possible FEs;
  - The user environment:
    - Definition of suitable models for the effects due to local sources of errors.
- All these aspects, in turn, drive different system features, e.g.:
  - The algorithms to evaluate the differential corrections and the associated residual errors; and
  - The maximum update intervals (refresh rate) for the data to be delivered to the users.

WHAT ABOUT SBAS?
EGNSS SoL for Aviation: EGNOS





EGNOS Architecture

EGNOS Ground Segment

EGNOS OS (V2) and DGPS services (1/2)

— As a WADGPS system, EGNOS OS (V2) provides an equivalent service to DGPS. Major differences and similarities are summarised as follows:

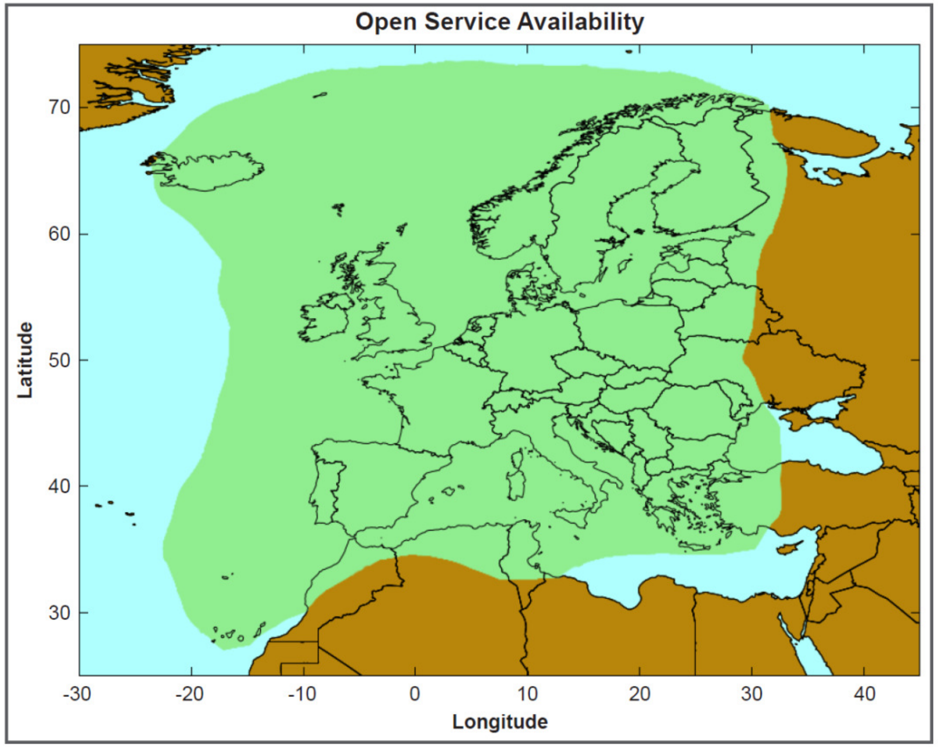
Service	DGNSS	EGNOS V2
Differential Corrections (Accuracy)	**Yes**: corrections are evaluated at each RS.	**Yes**: corrections are evaluated at the CPF based on RIMS measurements.
Quality of Corrections: UDRE (Integrity)	**Yes**: UDREs for each SV are evaluated at the RS and broadcasted to the users	**Yes**: UDREs (ephemeris and clock corrections only) for each SV and GIVEs for each IGP are evaluated and checked at the CPF; these are then broadcasted to the users.
Quality of corrections: check in the pseudo-range domain (Integrity)	**Yes**: additional checks in the pseudo-range domain are done at the IM station; if a problem is detected for a SV, the user is warned not to use that SV.	**Yes**: additional checks in the pseudo-range domain are done at the CPF and, locally, at each RIMS; if a problem is detected for a SV, the user is warned not to use that SV.

EGNOS OS (V2) and DGPS services (2/2)

Service	DGNSS	EGNOS V2
Quality of corrections: check in the position domain (Integrity)	**Yes**: additional checks in the position domain are done at the IM station; if a problem is detected, the user is warned not to use the system.	**Yes**: additional checks in the position domain are done at the CPF and, locally, at each RIMS; if a problem is detected, the user is warned not to use the system.
Quality of corrections: autonomous consistency check at the user level (Integrity)	**Yes**: it can be done at the user level based on augmented GNSS observations; the result is an error ellipse which describes the confidence levels in the position estimation	**Yes**: it can be done at the user level based on augmented GNSS observations; specifically, the same algorithm recommended for the DGPS case can be used; only the corrections are different.
PLs (Integrity)	**Not available**	**Available with aviation receiver** and RTCA standard **Not available** in EGNOS V2 with maritime standard

EGNOS OS (V2): accuracy

- EGNOS OS and DGPS are shown to have similar performance in terms of accuracy.



$$\begin{cases} HNSE \leq 3m \\ VNSE \leq 4m \end{cases} \quad 99\%$$

EGNOS OS minimum compliance area (EGNOS OS SDD)

EGNOS V2 (OS) as part of WWRNS (1/2)

– EGNOS V2 (OS) has the potential to meet the operational requirements indicated in the IMO 1046(27) for the most critical operation ("Navigation in harbour entrances, harbour approaches and coastal waters").

IMO 1046(27) requirements for the most critical operation		
	Requirement	**EGNOS V2 (OS)**
Accuracy	*"Where a radio-navigation system is used to assist in the navigation of ships in such waters, the system should provide positional information with an error not greater than 10m with a probability of 95%."*	**Yes**: *HNSE≤3m (99%)* over the EGNOS OS minimum compliance area.
Integrity	*"An integrity warning of system malfunction, non-availability or discontinuity should be provided to users within 10s."*	**Yes**: System integrity information is included in EGNOS messages and provided in accordance with a TTA requirement of *10s*.

EGNOS V2 (OS) as part of WWRNS (2/2)

IMO 1046(27) requirements for the most critical operation (cont'd)		
	Requirement	**EGNOS V2 (OS)**
Availability	"*Signal availability should exceed 99.8%*" (No requirement about system availability)	**Yes, most probably**: The signal availability is actually related to the provision of EGNOS corrections. It can be calculated according to the relevant (IALA R-121) recommendations for DGPS.
Continuity	"*When the system is available, the service continuity should be ≥99.97% over a period of 15min.*"	**Yes, most probably**: The service continuity is actually related to the uninterrupted provision of EGNOS corrections throughout the operation duration (*15min*). It can be calculated according to the relevant (IALA R-121) recommendations for DGPS

WHAT ABOUT SBAS?
SBAS performance

- The analysis of SBAS performance carried out by ESA highlighted that:

- SBAS is able to provide a generic user with the same type of data that DGPS provides. This consists of differential corrections and system integrity information.

- SBAS nominal performance has the potential to meet the IMO requirements for a component of the WWRNS

A two step approach

A two step approach is proposed

- The first step aims to promote the use of SBAS as a complement to DGPS.
    - This might be also a good opportunity for EGNOS (V2) to be recognised as a (regional) component of the WWRNS.
    - Receivers standards need to be developed for SBAS SIS

A two step approach

- The second step focuses on the identification of any nautical task requiring a more articulated integrity concept
- Discussions currently on going for the definition of the resilient PNT multisystem receiver are addressing user level performance requirements
- In case specific nautical tasks require integrity at use level, a new concept could be developed able to protect the users through dedicated PLs.
- Close cooperation with the maritime community is required to develop the concept. Several system aspects need to be considered, e.g.:Consolidated user requirements, together with the underlying operational concept and operational scenario; FEs identification and IR/CR apportionment; Complete characterisation of the operational environment, including the development of appropriate models for the local sources of errors;

Concluding remarks

- Two strategies are proposed, at a technical level, to promote the use of SBAS in maritime applications.
  - In the short term, SBAS can be offered to maritime users as a complement to DGNSS.
  - In the long term, the resilient PNT multisystem receiver shall satisfy general integrity maritime requirements. Should specific nautical tasks requiring integrity at user level be identified, a new integrity concept for maritime SoL applications should be developed in close cooperation with the maritime community