IALA World Wide Radio Navigation Plan

Edition 2

December 2012

Edition 1: December 2009

10, rue des Gaudines

78100 Saint Germain en Laye, France

Telephone: +33 1 34 51 70 01 Fax: +33 1 34 51 82 05

e-mail: contact@iala-aism.org   Internet: www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities

IALA

AISM Association Internationale de Signalisation Maritime

Document Revisions

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

Date	Page / Section Revised	Requirement for Revision
September 2012	Whole document	General updating INS replaced by inertial systems (INS is the IMO abbreviation for Integrated Navigation System) A.953(23) replaced by A.1046(27) Revised dates for GPS III & Galileo Revised dates and descriptions for the GNSS constellations and SBAS.

Table of Contents

Index of Tables

Index of Figures

Executive summary

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) exists to:

- harmonise standards for aids to navigation systems worldwide;
- facilitate the safe and efficient movement of shipping, and;
- enhance the protection of the maritime environment.

This IALA World Wide Radio Navigation Plan aims to build on individual National and Regional plans and identify the Radio Navigation components which will be key to the successful implementation of e-Navigation. One of the cornerstones of e-Navigation is the universal availability of robust position-fixing, navigation and timing services.

The plan provides guidance to IALA members regarding potential future developments, which will enable members to identify areas requiring resource allocation and research activity.

IALA World Wide Radio Navigation Plan

1 INTRODUCTION

1.1 General

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) was formed in 1957 as a non-government, non-profit making, technical association that provides a framework for aids to navigation authorities, manufacturers and consultants from all parts of the world to work with a common effort to:

- harmonise standards for aids to navigation systems worldwide;
- facilitate the safe and efficient movement of shipping, and;
- enhance the protection of the marine environment.

The functions of IALA include, among other things:

- developing international cooperation by promoting close working relationships and assistance between members;
- collecting and circulating information on recent developments and matters of common interest;
- liaison with relevant inter-governmental, international and other organisations. For example, the International Maritime Organization (IMO), the International Hydrographic Organisation (IHO), the Commission on Illumination (CIE), and the International Telecommunication Union (ITU);
- liaison with organisations representing the aids to navigation users;
- addressing emerging navigational technologies, hydrographic matters and vessel traffic management.

1.1.1 e-Navigation

e-Navigation is an International Maritime Organization (IMO) led concept based on the harmonisation of marine navigation systems and supporting shore services driven by user needs.

The working definition of e-Navigation as adopted by IMO is:

> *e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment.*

There are 3 key elements or strands that must first be in place before e-Navigation can be realized:

- Electronic Navigation Chart (ENC) coverage of navigational areas;
- a robust electronic position, navigation and timing system (with redundancy); and
- an agreed infrastructure of communications to link ship and shore.

1.1.2 Aim & Vision

The aim of IALA is:

> *Fostering the safe, economic and efficient movement of vessels by improvements and harmonisation of aids to navigation worldwide.*

while the Vision of IALA is:

> *Safe marine navigation in a world of:*
>
> - Larger and faster ships;

- Changing economy & technology;
- Stringent standards;
- Holistic approach (e-Navigation);
- Changing waterway use.

With this in mind, IALA has taken an initiative, as part of the strategy for the future of e-Navigation, by developing a World Wide Radio Navigation Plan.

1.2 Scope and Objectives

The 3 key elements of e-Navigation are identified above. This document focuses solely on the need to provide robust electronic position, navigation and timing (PNT) information, primarily via radio navigation systems. It presents the IALA position on current, developing and future PNT systems within the maritime environment.

This document is aimed at assisting in the formulation of policy for National and Regional Radio Navigation Plans.

It is also provided for IALA members and other administrations to assist them in offering their radio navigation systems to IMO as part of the WWRNS.

2 BACKGROUND TO SERVICE PROVISION

2.1 General

The IALA Aids to Navigation service provision mix is coming under increasing pressure. User requirements are becoming more demanding, whilst at the same time IALA members endeavour to deliver safety critical services at maximum value for money. This is in the context of long-term growth in shipping traffic and an increasingly litigious legal environment. Radio navigation itself is also adding new levels of complexity to the service provision environment and significant change is anticipated over the next two decades.

2.2 Institutional

In recent years, there has been a convergence of interests between the various institutional bodies in the international maritime world. To optimise e-Navigation, there will be an ongoing need for close co-operation between the International Maritime Organization (IMO), the International Hydrographic Organisation (IHO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

2.3 Regulatory

Globally, there are growing signs that an increasing number of National Administrations are ready to support further legislation to ensure maritime safety, environmental protection and security, for example:

- at IMO NAV 54 in July 2008, IMO agreed a schedule (2012-2018) for mandatory carriage of ECDIS on SOLAS vessels;
- IMO have defined an increasing number of Traffic Separation Schemes, with an IHO requirement to regularly resurvey these areas with a high degree of accuracy;
- the increasing number of multi-national data-sharing agreements, such as IMO's LRIT, the European Union's SafeSeaNet and the Baltic HELCOM Agreement; and
- the development of Marine Electronic Highways and Motorways of the Sea in high risk areas.

This is likely to result in greater commonality in service provision between different National Administrations. It may lead to a strengthening of IMO's role as regulatory requirements are implemented in a more stringent manner.

There are moves towards charging 'market rates' for the use of radio spectrum in some countries and proposals may be put forward for adoption of this approach internationally.

2.4 Commercial

There are key trends in the global shipping industry that are already having, and will continue to have, a large effect on the service to be delivered:

- the continued importance of the maritime sector in supporting global economic growth particularly on the Asia routes - in 2007 the world seaborne trade reached a record high of 8.02 billion tonnes[1];
- ships are becoming larger and faster – Maersk now operate eight vessels of the Emma Maersk class. These vessels are 397 metres long, 56 metres wide, can carry 11000 twenty-foot containers and are capable of more than 25 knots;
- the age profile of the world fleet – over the last decade, the average age of container ships and tankers has decreased markedly although more than 30% of the remainder of the world fleet is more than 20 years old; and
- a move towards increasingly sophisticated integrated bridge equipment, relying on electronic equipment to compensate for much reduced manning levels. The cost of such equipment is reducing in comparison to the overall cost of building and operating vessels.

The pressures on IALA members' service provision will increase as a result of these trends. The size, age and abilities of the international fleet are becoming more varied and this has a significant effect upon plans for introducing new AtoN services and equipment.

As service providers, IALA members must meet the demands of modern, state-of-the-art ships with fully integrated bridge systems as well as 30 year-old cargo ships with basic bridge and navigation equipment.

2.5 Operational

There are many changes taking place in the operational environment that present new challenges including:

- IMO's and IALA's support of e-Navigation;
- the widespread and growing reliance upon GNSS and its role underpinning navigation, situational awareness and communications for e-Navigation;
- growing deployment of local and specific Traffic Management Schemes to meet ever more stringent requirements at higher capacity levels; and
- the balance between traditional navigation skills and the role of new technological advances such as ECDIS and Integrated Bridge Systems.

The introduction of GNSS has encouraged mariners to navigate in areas and conditions in which they would not previously have done and the introduction of e-Navigation will further change the way that ships operate. As part of its introduction, it is essential to understand what happens when key e-Navigation components (e.g. GNSS) fail or are denied. Getting the human factors part of this right is also critical: before adopting the technology - safety, liability, on-board training and duty of care must all be considered.

e-Navigation means that international bodies (IMO, IHO, IALA, etc.) must work more closely together as the concept encompasses all their areas of responsibility.

[1] Review of Maritime Transport, 2008. United Nations Conference on Trade and Development (UNCTAD) Secretariat, United Nations, New York and Geneva, 2008.

In 2007, the IMO Sub-Committee on Safety of Navigation (NAV) agreed that there was a need to provide an internationally agreed alternative system for complementing the existing satellite navigation, positioning and timing services to support e-Navigation and recognised that potential backup systems could be made available[2].

2.6 Technical

Significant changes to underpinning services and systems are expected over the next two decades:

- the development and proliferation of GNSS services;
- the development of additional GNSS augmentation services;
- the deployment of AIS as an AtoN;
- further developments of AIS or complementary technologies, including Virtual AtoN;
- new technology radar that is not required to trigger existing Racons;
- the prospect of the international provision of eLoran;
- the evolution of e-Navigation with improved communications between stakeholders.

These new systems and services provide us with an ever-increasing array of options through which to optimise service level, and minimise risk and cost. At the same time, the need for co-ordination between IALA members, and with key stakeholders such as IMO has never been more important as we endeavour to ensure consistent levels of service provision on an international basis.

It must also be remembered that there will be a continuing need for a supporting backbone of physical AtoN, many of which are platforms supporting multiple systems, mixing radio and visual AtoN.

3 THE IALA WORLD WIDE RADIO NAVIGATION PLAN

3.1 Overview

The aim of this section is to list the existing and emerging radio-navigation systems as well as the augmentation systems required to provide local, regional and worldwide distribution. These systems or a combination of them can be used as a source of position, navigation and timing (PNT).

The only PNT systems that currently meet IMO requirements as a WWRNS on a global basis are GPS and GLONASS. Therefore marine navigation is highly dependent on GNSS for PNT information. This provides real time information regarding the position of the vessel, and also a direct input into such onboard systems as:

- Integrated Bridge Systems;
- ECDIS;
- ARPA / radar;
- GMDSS;
- AIS;
- LRIT;
- VDR.

2 Para 13.24, Sub-Committee on Safety of Navigation (NAV), 53rd session; International Maritime Organization, 2007.

These inputs influence both the onboard decision-making process on each vessel, and also that on other vessels and ashore by relaying the vessel information via AIS.

The shore-based marine infrastructure is also dependent on PNT information for:

- position reports to VTS;
- LRIT;
- synchronising time slots in AIS;
- synchronising flashing lights;
- synchronising communication systems.

Robust PNT information will become an essential foundation of e-Navigation, and requires three complementary components:

- a core Global Navigation Satellite System (GNSS);
- augmentation of GNSS to ensure that GNSS system performance is fit for purpose;
- adequate backup in the event of GNSS system failure.

Potential components of a World Wide Radio Navigation System are depicted below:

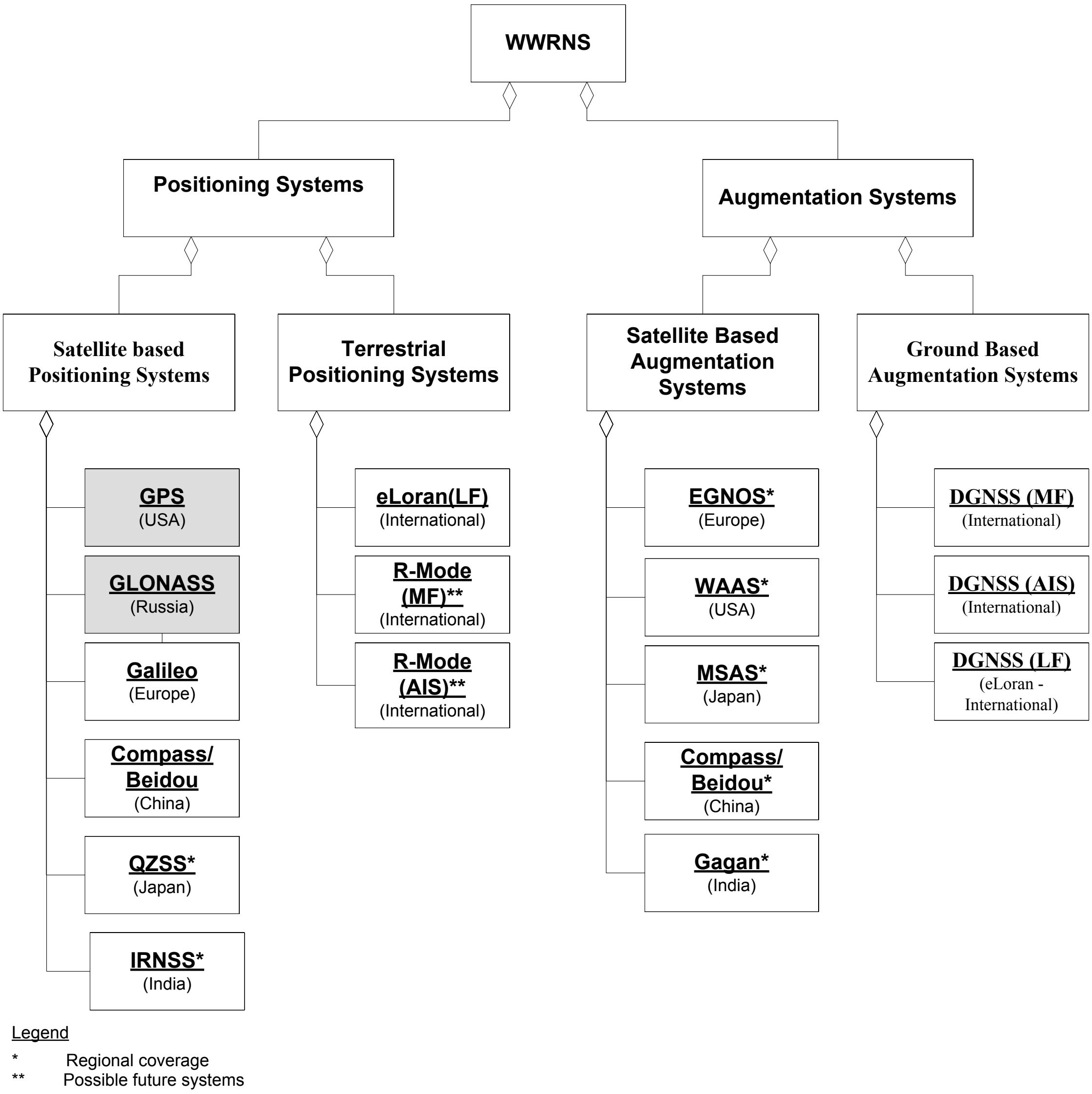

Figure 1 Candidate systems to provide robust positioning, navigation and timing. The grey shadowed Systems are already identified by IMO as part of a WWRNS.

It should be noted that:

- only terrestrial/ground-based components are operated by IALA Member Administrations;
- Space Based Augmentation Systems (SBAS) transmit via satellites, but require ground station infrastructure including reference stations.

3.1.1 Requirements

Requirements for navigation systems are generally described as their ability to meet five core functions:

- accuracy;
- availability;
- continuity;

- integrity;
- coverage;

These functions are defined in other publications, such as the IALA Aids to Navigation Guide (NAVGUIDE). Marine requirements standards are summarised in IMO Resolutions A.1046(27) World-Wide Radio-Navigation System[3] (see Annex A), and A.915(22) Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System[4].

The ability of differing technologies to provide coverage for different phases of navigation is shown below:

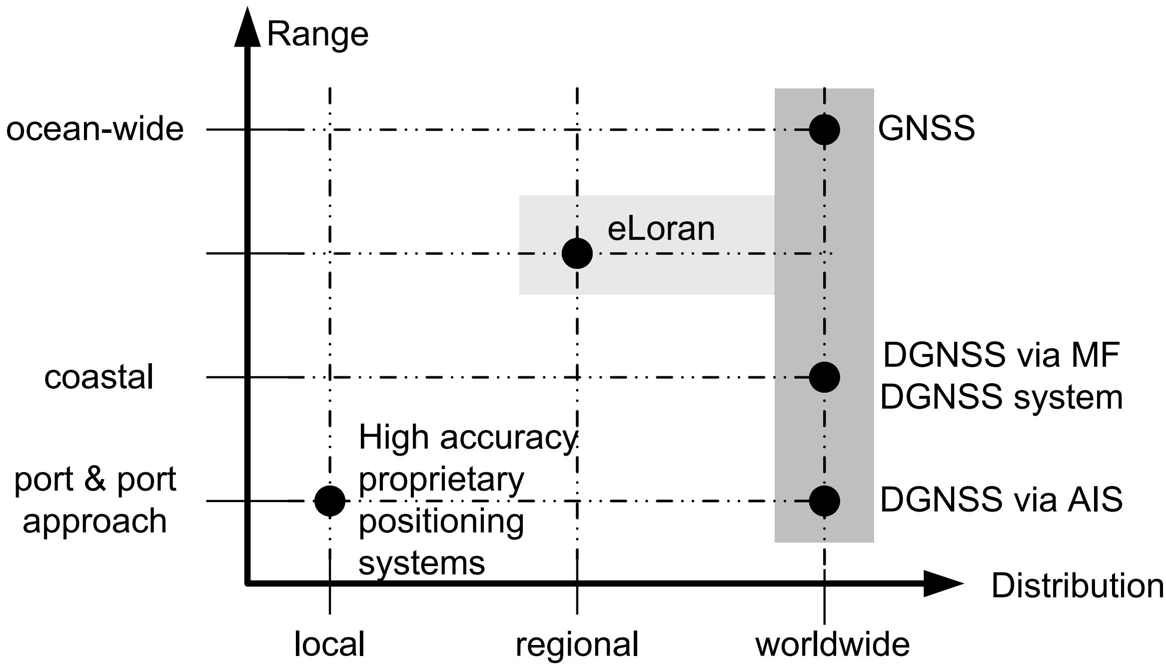

Figure 2 Radio navigation systems - distribution and range

High accuracy proprietary positioning systems include developments such as Real Time Kinematic GNSS and pseudolite technology, which generally rely on line-of-sight communications links.

A guarantee of service provenance and security, in the form of Signal Authentication, may also be a future requirement.

GNSS receiver technology is defined in the IEC 61108 series of standards and incorporates Receiver Autonomous Integrity Monitoring (RAIM).

It is anticipated that a future 'e-Navigation' receiver will incorporate core GNSS, augmentation and backup capability within a single unit, the 'Integrated PNT Receiver', and this is discussed further in Section 5.

3.1.2 Limitations of GNSS

GNSS systems are known to be very reliable when it comes to Quality of Service (QoS), but this is dependent in the longer term on the Service Providers' continued investment in maintaining an adequate constellation of operational satellites. In 2000 the GLONASS system was reduced to a minimum constellation, although this has since recovered with an increase in replenishment

---

[3] IMO Resolution A.1046(27) World-Wide Radio-Navigation System

[4] IMO Resolution A.915(22) Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System

launches and improved satellite reliability. In April 2009 the United States Government Accountability Office warned that the probability of having the core 24-satellite GPS constellation may fall to 0.8 (80%) over the next few years, and hence have a significant impact on GPS services[5].

The User should also be aware of these systems' short-term vulnerability, mainly a result of the very low received signal strength. Since the Volpe Report[6] focusing on GPS vulnerability, was published in 2001, the awareness of the vulnerability of all GNSS systems to both intentional and non-intentional interference has increased[7]. Temporary interruptions of GNSS are not expected to be frequent, but would have a high impact on Users.

3.2 Global & Regional Navigation Satellite Systems

3.2.1 GPS

The Global Positioning System (GPS) is a multi-use, space-based radio navigation system owned by the U.S. Government, and operated by the U.S. Department of Defense. GPS was put into full operation in mid 1995. The constellation is fully populated at present, with a number of in-orbit spares, although some units have exceeded their design life. Accuracies are well within the declared (≤9m 95%) target[8] and an enhanced ground control segment has improved monitoring. A modernization program aims to improve the accuracy and availability for all users and involves new ground stations, new satellites, and four additional navigation signals: three new civilian signals known as L2C, L5 and L1C and a new military code called M-Code. Operations with L2C can be expected by 2016, Full Operational Capability for L5 is expected by 2020 and L1C by 2021.

The next generation of satellites, GPS III, is in its design stage with first launch expected in 2014 and a full constellation sometime after 2020.

3.2.2 GLONASS

GLONASS is a former Soviet Union developed GNSS system, now owned and operated by the Russian Space Forces. Development of GLONASS began in 1976, with a goal of global coverage by 1991. Beginning in 1982, numerous launches added satellites to the system until the constellation was completed in 1995. The system was not replenished for several years and performance became degraded, however this situation has now reversed and the Russian Federation is committed to maintaining a full system. Recent launches have included the improved GLONASS M satellites with a second civil signal. The first of the new GLONASS-K satellites, with a third civil signal on L3, was launched in 2010. This range of satellites will also carry differential corrections, integrity information and search and rescue functions. The future GLONASS K-M system is at the requirement definition stage and it has been announced that a code division multiple access (CDMA) signal, inter-operable with GPS will be provided.

3.2.3 GALILEO

Galileo is the European GNSS designed to be interoperable with other GNSS, managed and operated under civil control. It is currently under development by the European Space Agency with funding by European Union. Galileo is aiming at providing an Open Service (OS), providing positioning and synchronisation information intended for high-volume satellite radio-navigation applications, a Commercial Service (CS) for added value professional or commercial applications, and a Public Regulated Service (PRS) restricted to government-authorised users requiring high-

---

5 Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities; U.S. Government Accountability Office, May 2009.

6 Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning Service; Volpe National Transportation Systems Centre; September 2001.

7 IALA Recommendation R-129 on GNSS Vulnerability and Mitigation Measures, December 2008.

8 Table 3.8.3 GPS Standard Positioning Service Performance Standard; 4th Edition; U.S. Department of Defense, September 2008

level of service continuity. Galileo will in addition provide a Search and Rescue Service (SAR), in support of the COSPAS-SARSAT.

Deployment started in October 2011 with the launch of the first two In Orbit Validation (IOV) satellites, with a further two due to be launched in October 2012. The target is to reach Initial Operational Capability (IOC) by 2014-2015 starting with a constellation of 18 first generation satellites, which will support the provision of continuous but limited service provision starting in the 2014-2016 timeframe. Complete Galileo Service Provision is due to start in the period 2018-2020 based on the Galileo Full Operational Capability (FOC) configuration and the fully deployed 30 satellites constellation. The first generation of Galileo will incorporate a number of features that were not part of previous GNSS systems. These include a signal in the E1 band with the advanced Multiplex Binary Offset Carrier modulation with improved performances, while ensuring both compatibility and interoperability with GPS and with other systems.

3.2.4 BeiDou (COMPASS)

BeiDou is a GNSS being developed by China to provide positioning, navigation and timing services to worldwide users. It can also provide wide area differential services with the accuracy of 1m and short messages services with the capacity of 120 Chinese characters each time. In 1994, China started the feasibility study of the BeiDou System. In 2000, two BeiDou experimental satellites were launched to begin a regional system. In 2004, China started to construct the full/final BeiDou Navigation Satellite System, which is now a global system comprising of 11 satellites and is to be completed by 2020.

The BeiDou Navigation Satellite System space constellation will consist of five GEO satellites and 30 non-GEO satellites (27 in medium earth orbit and 3 in inclined geostationary orbit).There will be two levels of service provided; free service to civilians and licensed service to Chinese government and military users. The free service will have 10 metre position accuracy and can synchronize clocks with an accuracy of 10 ns, and measure speeds within 0.2 m/s.

As of September 2012, fifteen BeiDou satellites had been launched. It is planned to provide initial operation service capacity for Asia-Pacific users (within the service area) by the end of 2012, and the system will be fully established by 2020, serving the global customers and becoming a component of GNSS for e-navigation.

3.2.5 QZSS

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on 3 satellites in eccentric, highly inclined orbits guaranteeing always one satellite in visibility of Japan with a minimum elevation angle of 60 degrees. Each satellite will transmit 6 signals in the L-band: 3 in L1, one in E6, one in L2 and one in L5.

One of the signals aims to provide sub-meter accuracy and integrity while maintaining compatibility with SBAS. The signal in E6 aims to support a commercial service with high data rate (2 kbps). The other signals are GPS-like signals, including L2C and L1C standards.

3.2.6 IRNSS

The Indian Regional Navigational Satellite System (IRNSS) will, as an independent navigation system, cover the Indian region with a space segment of 3 GEO satellites and 4 Inclined Geosynchronous Orbit (IGSO) satellites. The inclination of the orbital plane of the IGSO satellites is low, so that all the satellites can be seen simultaneously over India. Three IRNSS services are anticipated:

- Open Service using signals in the L5 and S bands;
- Precise Positioning Service using signals in the L5 and S bands;
- Restricted Access Service using signals in the L5 band only.

The Open and Precise services target dual frequency users but it is also intended to compute and broadcast ionosphere-corrections to support single frequency users. Because of the limited coverage of the IRNSS network of reference stations the satellites will, apart from the navigation payload, also include a dedicated C-band uplink/down-link ranging payload to support precise satellite orbit determination.

3.3 GNSS Augmentation

3.3.1 Ground Based Augmentation Systems (GBAS)

3.3.1.1 IALA Radiobeacon DGNSS

IALA radiobeacon DGNSS remains the internationally accepted means of providing DGNSS corrections and integrity information to maritime users. It is defined by international global standards, with regional harmonisation of frequencies via IALA and ITU.

IALA members will continue to provide radiobeacon differential GNSS services. This service will be developed in line with GNSS evolution to monitor the performance of GNSS, to provide timely integrity warnings of service degradation and provide comprehensive but cost-effective augmentation[9].

IALA members will:

- Continue to provide the IALA radiobeacon DGNSS service in line with IALA recommendation R-121[10];
- Recapitalise the existing DGNSS infrastructure, where necessary, to avoid system obsolescence. Consideration should be given to the recapitalisation options, as described in IALA Recommendation R-135;
- Review their service provision to take account of GNSS developments;
- Continue to encourage and support the IMO's acceptance of IALA radiobeacon DGNSS into the World Wide Radio Navigation System (WWRNS); and
- Investigate the standardisation and delivery of high precision DGNSS to support aids to navigation management, harbour approach and docking.

3.3.1.2 AIS as a GBAS

Automatic Identification System (AIS) is a ship to ship and ship to shore data broadcast system, operating in the VHF maritime band. Its characteristics and capability make it a powerful tool for improving the safety of navigation and efficiency of shipping traffic management.

An AIS unit is a VHF radio transceiver capable of exchanging information such as station identity, position, course, speed, length, ship type and cargo information etc., with other ships and suitable receivers ashore. AIS uses self-organising TDMA, with synchronisation usually provided by GPS, though other timing sources are possible and base stations can act as the timing reference.

Under the SOLAS Convention AIS became mandatory for ships on international voyages since 2004. Also many administrations established regional networks to improve marine traffic control. AIS Base Stations may have the capability of providing DGNSS corrections to onboard AIS equipment using standardised transmissions (Message 17) as described in IALA Recommendation A.124[11], however most vessel installations do not distribute AIS-derived DGNSS information to other onboard systems.

---

[9] IALA Recommendation R-135 on The Future of DGNSS; Edition 2, December 2008.

[10] IALA Recommendation R-121 on The Performance and Monitoring of a DGNSS Service in the band 283.5-325 kHz; Edition 2, December 2004.

[11] Appendix 2, IALA Recommendation A-124 On Automatic Identification System (AIS) Shore Station and Networking Aspect relating to the AIS Service, Edition 1.3, December 2008.

The use of AIS Message 17 increases the number of vessels which benefit from DGNSS transmissions with respect to better accuracy and integrity in their AIS position reports.

3.3.2 High accuracy systems

3.3.2.1 Carrier phase augmentation systems (RTK)

RTK satellite navigation is a technique used in land survey and in hydrographic survey based on the use of carrier phase measurements of the GNSS signals where a single reference station provides the real-time corrections, providing up to centimetre-level accuracy. RTK can only be used in localised regions.

RTK follows the same general concept as DGNSS, but uses the satellite's carrier as its signal, not the messages contained within. The improvement possible using this signal is potentially very high, at about 2 mm.

In practice, RTK systems use a single base station receiver and a number of mobile units. The base station re-broadcasts the phase of the carrier that it measured, and the mobile units compare their own phase measurements with the ones received from the base station. There are several ways to transmit a correction signal from base station to mobile station. The most popular way to achieve real-time, low-cost signal transmission is to use a radio modem, typically in the UHF band. In most countries, certain frequencies are allocated specifically for RTK purposes. Most land survey equipment has a built-in UHF band radio modem as a standard option.

Although these parameters limit the usefulness of the RTK technique in terms of general navigation, it is perfectly suited to roles like surveying harbours and potentially, docking. In this case, the base station is located at a known surveyed location, often a benchmark, and the mobile units can then produce a highly accurate map by taking fixes relative to that point.

3.3.2.2 Pseudolite Systems

Pseudolite is a contraction of the terms “pseudo” and “satellite". It refers to a signal transmission system that is not a real satellite but performs the function comparable to a satellite. Pseudolites are ground based installed signal transmitters mainly developed for testing and development of new GNSS applications. Each Pseudolite is equipped with a GNSS signal generator and an antenna to transmit and broadcast the GNSS signals. Depending on the environmental conditions the area of availability is limited to local applicability and can cover a range from only a few square kilometres up to around 100 square kilometres. Furthermore the range of each transceiver's signal depends on the power available to the unit.

The advantage of Pseudolites consists in the independence of GNSS. Pseudolites can be used in situations where normal GNSS signals are either blocked/jammed or simply not available.

Related to poor VDOP values only two-dimensional positioning becomes possible. This is due to the constellation of the transmitters being located almost in the same plane.

3.3.3 Satellite Based Augmentation Systems (SBAS)

The Wide Area Augmentation System (WAAS) has been implemented by the US Federal Aviation Authority to support the use of GPS for general and commercial aviation over the Continental United States. It was recently extended to cover parts of Mexico and Canada. At present the WAAS architecture includes 38 reference stations, 3 master stations, 4 up-link stations, 2 geostationary satellite links and 2 operational control centres. WAAS provides both differential correction services and an additional GPS-type ranging signal from each satellite.

EGNOS is the European SBAS and currently provides an SBAS service in the L1 band through two GEO transponders on INMARSAT satellites, comprising an Open Service operational since October 2009, and a Safety of Life service declared operational in March 2011. A third GEO transponder on ARTEMIS is used to support system upgrades. An EGNOS system upgrade is currently in the definition phase, targeting certified operations by 2019, and aiming at improved performances of the legacy L1 band services (including for the provision of additional services), dual-frequency GPS and Galileo augmentations, and extended geographical coverage.

In Japan, the Multi-Satellite Augmentation System (MSAS) is an SBAS similar to EGNOS and WAAS. MSAS is already in its initial operational capability phase with 2 GEO-links using the L1 band via dedicated satellites shared with communications and meteorological missions.

India is developing a GPS-Aided Geo Augmented Navigation system (GAGAN), which is an SBAS similar to WAAS and EGNOS. GAGAN includes 8 reference stations, 1 mission control centre, 1 uplink station and 1 GEO link through the L1/L5 transponder on the INMARSAT 4-F1 satellite. The full operational capability is expected for 2013 by when the system would have been extended with an additional master control centre, an additional up-link station, 2 additional GEO links (L1/L5) plus one in-orbit spare and more reference stations.

Russia is implementing an augmentation to GLONASS called SDCM (System for Differential Corrections and Monitoring) and the first geo-stationary satellite has been deployed. All SBAS require a widespread network of ground reference stations, linked to the satellite uplink facility, in order to function correctly.

3.4 The Future of GNSS

3.4.1 Current and Planned Evolution of Space-based GNSS Capabilities

Evolution of the GNSS infrastructure needs to be considered, because there are several opportunities for fulfilling emerging user needs by provision of:

- augmentation services to all constellations in view to improve the performance obtained with GPS signals alone, in terms of accuracy, integrity, availability or robustness;
- additional channels for supporting the dissemination of augmentation data at regional level, both for safety-of-life and mass-market applications and to service users in the civil aviation, maritime and land domains;
- additional navigation signals at higher frequencies (S, C-band) for better performance (accuracy, robustness) and better interoperability with the evolution of spectrum utilization for mobile communications.

3.4.2 GNSS Strategy

At some stage (around 2020) there are likely to be three or four GNSS available, providing a total of more than 100 satellites, with multiple frequencies, inherent integrity monitoring and warning. This number of satellites will make Receiver Autonomous Integrity Monitoring (RAIM) a reliable proposition. The requirement for separate (satellite or ground-based) augmentation may need to be re-examined at that stage and it may be appropriate to consider phasing out existing augmentation systems with those developments in mind. However, the concerns about the vulnerability of GNSS will remain and there will still be a case for alternative electronic position fixing systems and for independent verification and warning systems.

It should also be noted that current GNSS providers do not accept liability for the service they provide.

System												
GPS								L2C				L5
GLONASS	FOC											
GALILEO						IOC				FOC		
COMPASS												
SBAS												
IALA DGNSS												
eLoran												
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020

Figure 3 Current and anticipated Radio Navigation Systems

3.5 eLORAN / CHAYKA

GNSS (in particular GPS) has become the primary means of navigation in many maritime applications. However, the vulnerability of GNSS to accidental or deliberate interference is well known and the need for more than one position input to e-Navigation is recognised.

It is noted that Loran/Chayka is the only wide area terrestrial radio-navigation system currently available. This system generally provides coverage including and exceeding the coastal phase of navigation and is usually provided by more than one administration working in partnership.

It is also noted that most countries with Loran facilities are now committed to retaining them for the foreseeable future as a backup or complement to GNSS.

Members of IALA with Loran/Chayka facilities within their jurisdiction are encouraged to retain them in operation and make plans to upgrade them to eLoran capability, so that they can form part of the WWRNP. IALA also encourages its Members to give full support to the development and standardisation of eLoran, so that the system can be recognised as a component of e-Navigation. The necessary performance and technical standards are currently under development by RTCM Special Committee 127.

The key differences between existing systems and eLoran can be shown in tabular form:

Table 1 Key differences between existing systems and eLoran

Feature	Existing Loran-C / Chayka	eLoran
Transmitter	Tube or solid state	Solid state
Timing control	System Area Monitoring or Time of Emission control	Time of Emission control
Chain Synchronisation	Chain controlled by Master Station	Each transmitter linked to UTC
Data transmission	None or Eurofix	Loran data channel
Receiver Mode	Hyperbolic; Chain selection, manual or automatic	Ranging; All-in-view
Use of Additional Secondary Factor (ASF) corrections	None or internal database	Database mapped within receiver
Differential Loran usage in port and port approach areas	No	Yes
Accuracy	Nominal 400m	8-20m where differential Loran corrections provided; <100m elsewhere

3.6 VTS shore based Radar

VTS and Coastal Surveillance (CS) radars are of significant use, as they deliver non-cooperative target detection and tracking and do not rely on an external position fixing system. In contrast, AIS reports rely on the shipborne AIS unit being turned on and configured correctly as well as on an external position fixing system.

In case of primary position fixing system (GNSS) failure, VTS/CS radar can provide navigational information to a vessel, for example track information on radar targets. It is also technically possible to transmit a complete situation image for a certain area, but this would require suitable user equipment and an allocated communications link. VTS does not provide an alternative timing reference.

VTS/CS centres can monitor agreement between radar and AIS data and may communicate relevant alarms by manual or automatic means when disagreement occurs in critical areas. This also includes radar targets with no corresponding AIS reports.

3.7 Racons and Shipborne Radar

3.7.1 Shipborne radars

The IALA WWRNP does not address shipborne radars but the characteristics of the radars used onboard affect the use of radar AtoN (radar beacons or racons). New Technology (NT) radars are now being manufactured. Characteristics to be taken into account include the use of pulsed magnetron transmitters vs. solid state modulated pulse transmitters, pulse compression, and use of raw video vs. video processing to enhance small targets in clutter. The operation of passive radar target enhancers i.e. reflectors is unlikely to be affected by a change in transmission and video processing technology.

Note that regulations affecting shipborne radar have recognised the triggering characteristics of racons by NT radar and have removed the requirement for triggering and processing of racons when operating in S band. To date there is no change to regulations with regards to X band shipborne radar.

3.7.2 Radar map-matching / Radar tagging

More sophisticated shipborne radars may incorporate a facility to locate the vessel by means of tagging of radar-conspicuous targets at known locations. Correlation of a shoreline on radar can also be overlaid on an electronic chart display to give confidence in the position displayed on the latter, although the value of this technique varies with the radar conspicuity of the area.

3.7.3 Racons

Uniquely identifiable racons are highly important when navigating in low visibility conditions, in the night or under adverse weather conditions. Racons rely on the excitation by the shipborne radar; in contrast AIS AtoNs rely on an external position fixing system. However, racons are not PNT systems, since they do not provide a timing reference.

When applying solid state transmitters, excitation range of traditional racons will diminish because of lower maximum transmitted power, or mismatch of frequencies. The development of racons and NT radar to optimise the combined performance would be beneficial.

3.8 Automatic Identification System (AIS)

AIS can also be applied to Aids to Navigation (AtoN) to improve and enhance services provided to mariners.

A special type of Automatic Identification System (AIS) station fitted to an Aid to Navigation (AtoN AIS) can provide a positive identification of the aid. Furthermore it can provide:

- the position and identity of floating AtoN (i.e. buoys) by transmitting current position and monitoring whether they are on position (Message 21);
- real-time information for performance monitoring, including state of 'health' (Message 6);
- additional information such as actual tidal height and local weather to surrounding ships or to a shore authority (Message 8).

The AIS service may also enhance and complement Aids to Navigation functionality by providing virtual AIS AtoN.

It should be noted that AIS is essentially a communications system, not a PNT system, and only provides position information obtained from another source (e.g. GPS). Further developments in AIS Technology are anticipated.

3.9 Potential extension of Existing Systems

3.9.1 R-Mode on MF beacon and AIS

At present the two maritime systems with widespread distribution, namely the IALA MF beacon system and the AIS Services, would be candidates for modification to add R-mode functionality.

The proposed functionality of the Ranging-Mode is the provision of timing information from shore to ship. The shipboard radio receiver may then calculate a distance (range) to the transmitter. Using several such calculations from a number of different transmissions, the shipboard equipment is able to calculate the ship position. Coverage, geometry and interference questions would need to be investigated.

The provision of R-Mode services via MF or VHF transmissions would require the availability of an accurate non-GNSS timing source at the transmitter. This could be provided by high stability clocks at each station, however this would be expensive and it is more likely that this would be sourced from a low frequency radio time clock or eLoran.

4 NON-RADIO POSITION FIXING

Loss of GNSS position and time inputs may render AIS and ECDIS unusable. Therefore it could be advantageous to use a backup system based on inertial systems that is able to continue providing an electronic position with a similar level of accuracy for a specified time period.

Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and attitude of an object relative to a known starting point.

The performance and costs of inertial systems heavily depend on the different available technologies.

At the current stage even high grade inertial systems cannot be considered as a primary backup to GNSS positioning sensors.

It is necessary to integrate inertial systems with other sensors like speed log, magnetic sensors or with GNSS to compensate for the drift in positioning errors.

However, low-cost inertial systems are developing and it is possible that in future their performance may make them useful as a short-term backup and they may also have a role in improving integrity and position stability.

Inertial systems are already used in combination with GNSS on some vessels for specialised applications, such as hydrographic survey, where the short-term stability of position is valuable.

4.1 Integration of visual information

An 'electronic pelorus' is proposed, which would enhance the functionality of the traditional shipboard compass for taking bearings of fixed and floating objects, by capturing bearings that would then be automatically recorded for use within the electronic navigation system.

An integrated electronic pelorus must be capable of visually sighting an object and transferring a line of position (LOP) to an electronic navigation system display, possibly by pulling a trigger or pressing a button. Further functionality may include:

1. The ability, once an object has been sighted, to automatically cross-reference it through a graphical means with charted features, or using databases such as lists of lights, sailing directions or a world fleet database. This might result in the cross-reference being made through AIS technology so that once an object, such as a lighthouse or another vessel, has been sighted a photographic image and characteristics of the object is simultaneously displayed.
2. Bearings of other vessels, taken to assess risk of collision, may be associated with other target tracking features from radar or AIS to offer more effective tracking and to provide information redundancy and internal confirmation and checking.
3. Visual images from the pelorus may be able to be enhanced with low-light or infrared technology.
4. LOPs taken with the pelorus may be recorded within the Voyage Data Recorder (VDR) or other equipment so that a Master can assess the level of activity of watch keepers.

4.2 Terrain Referenced Navigation

Another potential source of position information is the use of a vector chart together with echo sounder measurements, using a map matching algorithm based on a digital terrain model (DTM) to correlate measured depths against known charted data.

The terrain navigation system (TNS) can be viewed as an independent component of the navigation system whose primary function is to provide position measurements. Such a TNS could be integrated together with the inertial navigation system (INS) and the connected GNSS receiver. In other systems it might integrate with a dead-reckoning system or serve as an independent position source. Terrain navigation can also enhance the total navigational integrity by providing a position estimate supplementary to INS and GNSS. This is of interest for instance for vessels when they operate in an area where GNSS can be subject to jamming or spoofing. TNS are currently being tested and used for navigation in autonomous underwater vehicles and on submarines.

The terrain correlation processor can be connected to INS to run the terrain correlation. Calculated position fix and associated uncertainty is sent back to the navigation system to limit the position error drift. The terrain correlation processor runs with any sensor providing bathymetric data, for instance a multibeam echo sounder or single beam echo sounder.

One essential issue for the use of the TNS is that the available digital terrain models often have poor resolution and accuracy, except for dedicated areas where accurate high resolution (1 – 10 m horizontal resolution) DTMs have been surveyed. Terrain navigation accuracy depends on algorithm characteristics, sensor accuracy, map accuracy, map resolution and not least terrain suitability. All terrain navigation algorithms need terrain variation to work at all.

Within the context of e-Navigation, it is feasible for each vessel to continuously log echo sounder information against current position information, and relay this information to a shore station. Shore authorities may then conduct on-going automatic checks of this information in comparison with the electronic chart, with the aim of identifying erroneous:

- information, indicative of PNT system failure or spoofed data;
- hydrographic data, or indicating areas requiring new survey.

5 THE e-NAVIGATION PNT CONCEPT

It is envisaged that an integrated radio navigation device may be considered to be a core component of any e-Navigation equipment fit. Within e-Navigation an open and modular integrated PNT concept was developed[12] to provide resilient position navigation and timing data. The proposed PNT concept uses any available IMO recognised radio navigation system simultaneously to provide the best electronic position fix for the ship. Furthermore the PNT concept supports the exploitation of modernization processes in radio navigation systems (space-based and terrestrial), ship-side sensors and shore-side services. In addition the PNT concept is an open framework supporting the usage of any sensors, services and data sources improving the accuracy or assessing the integrity of provided PNT data and applied components.

The “Integrated PNT System” is the required overlay of GNSS as part of WWRNS, shore-side PNT services (PNT relevant MSP), ship-side components (PNT Module), and communication links, whose integrated use ensures the accurate and reliable provision of ships’ PNT data to applications during all phases of vessel navigation in a timely, complete and unambiguous manner (Figure 4).

The PNT concept makes use of shore services as offered by augmentation services, backup services and the application of future PNT relevant MSI (Maritime Safety Information).

On the ship the PNT concept consists of a PNT unit included as part of an advanced integrated navigation system (INS) (Figure 5) and enables the use of a variety of PNT relevant sensors and sources. Their combined use exploits the available redundancy by processing raw data to generate the best PNT. Through integrity monitoring the PNT unit has the potential to identify and provide the best PNT data and to indicate the current accuracy and integrity. Today’s INS concept supports the integrated PNT approach.

[12] e-NAV11-output-19 INF paper to NAV 58 - e-Navigation implementation plan

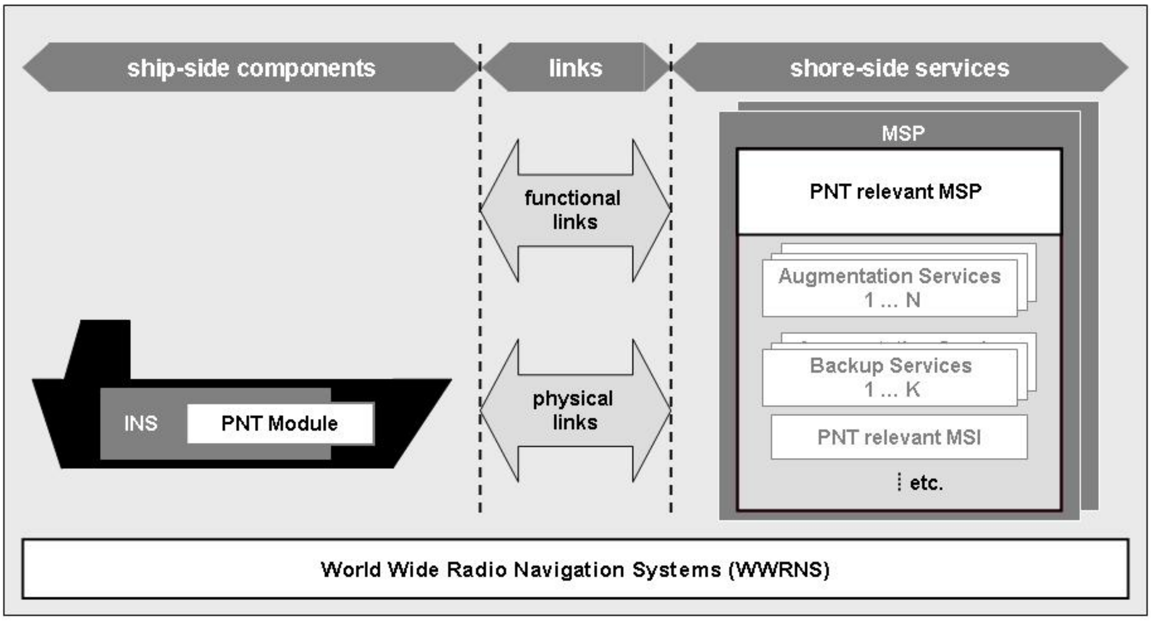

Figure 4 Generic architecture of the maritime Integrated PNT System

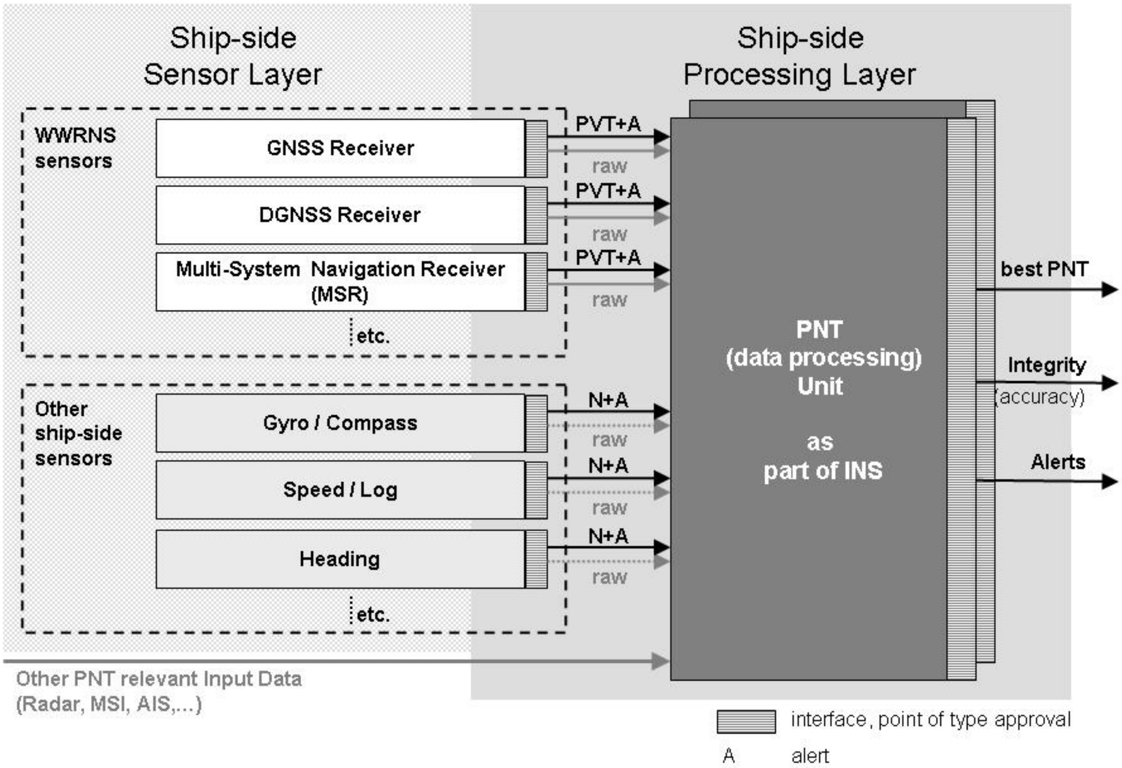

Figure 5 Ship-side PNT module with PNT (data processing) Unit

6 DELIVERING THE PLAN

IALA Members are encouraged to participate in realising the robust PNT element of e-Navigation by:

- **contributing to the development of e-Navigation**;

- **contributing to the development of GNSS and Space Based Augmentation systems** – by representing maritime interests to the Operators of these systems;
- **continuing to provide Internationally recognised DGNSS Services**, by:
  - recapitalising the existing DGNSS infrastructure as required to avoid system obsolescence;
  - reviewing their service provision to take account of GNSS developments;
  - continuing to encourage and support the IMO's acceptance of IALA radiobeacon DGNSS into the World Wide Radio Navigation System (WWRNS); and by
  - investigating the standardisation and delivery of high precision DGNSS to support aids to navigation management, harbour approach and docking.
- **seeking to provide sufficient and appropriate levels of contingency support for GNSS, including**:
  - where Loran/Chayka facilities exist within their jurisdiction, to retain them in operation and make plans to upgrade them to eLoran capability;
  - giving full support to the development and standardisation of eLoran, so that the system can be recognised as a component of e-Navigation.
- **responding to Developments in Marine Radar Technology** – which may require the replacement of existing radar beacon installations with units adapted to 'New Technology' radars;
- **developing the AIS service as an Aid to Navigation**;
- **contribute to the trials and development of new systems to enhance marine navigation** e.g.:
  - R-Mode of MF beacons or AIS;
  - Non-radio techniques, including Inertial Navigation, the 'Electronic Pelorus' and Terrain Referenced Navigation.
- **continuing to provide short range aids to navigation as contingency systems, based on risk analysis** - taking into account all potential changes in the service provision environment.

  This includes trends, types, volume and mix of traffic, local hazards, areas of traffic convergence/separation, environmental considerations and changes to other risk mitigation measures.

7 GLOSSARY OF TERMS

AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
AtoN(s)	Aid(s) to Navigation
CDMA	Code Division Multiple Access
CIE	Commission on Illumination
COMPASS	Chinese GNSS System
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DTM	Digital Terrain Model
ECDIS	Electronic Chart Display Information System
EGNOS	European Geostationary Navigation Overlay System
eLoran	Enhanced Long Range Navigation system
ENC	(Hydrographic Office approved) Electronic Navigation Chart
GALILEO	European GNSS System
GBAS	Ground Based Augmentation System
GEO	Geostationary Earth Orbiting satellite
GLONASS	Global Navigation Satellite System (Russian Federation)
GMDSS	Global Maritime Distress & Safety System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (US)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IGSO	Inclined Geosynchronous Orbit satellite
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
INS	Integrated Navigation Systems
IRNSS	Indian Regional Navigational Satellite System
ITU	International Telecommunication Union
LOP	Line of Position
LRIT	Long Range Identification & Tracking
MEO	Medium Earth Orbit satellite
MF	Medium Frequency
MSAS	Multi-Satellite Augmentation System
NAV	IMO Safety of Navigation Sub-Committee
PNT	Position, Navigation & Timing
QoS	Quality of Service

QZSS	Quasi-Zenith Satellite System
RACON	RAdar BeaCON
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Radionavigation
RTK	Real Time Kinematic (GNSS)
SBAS	Satellite Based Augmentation System
SDCM	System for Differential Corrections and Monitoring
SOLAS	Safety of Life at Sea (IMO Convention)
TNS	Terrain Navigation System
TOA	Time of Arrival
TOE	Time of Emission
UHF	Ultra High Frequency
UPS	Uninterruptible Power Supply
VDR	Voyage Data Recorder
VHF	Very High Frequency
VTS	Vessel Traffic Services
WAAS	Wide Area Augmentation System
WWRNS	World Wide Radio Navigation System

ANNEX A SUMMARY OF REQUIREMENTS

IMO Resolution A.1046(27) World-Wide Radio Navigation System (WWRNS) is summarised in Table 2.

Table 2 Summary of Requirements

Phase of Navigation	Accuracy Requirement	Availability Requirement	Continuity Requirement	Integrity warning
Ocean Waters	100m (95%)	99.8%	N/A	As soon as practicable by Maritime Safety Information (MSI) systems.
Harbour Entrances, Harbour Approaches and Coastal Waters	10m (95%)	99.8%	99.97% over 15 minutes	Within 10 s. (system considered available when it provides the required integrity for the given accuracy level)