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**Final draft of Chapter 4 (on e-navigation) for the 2018 Edition of the IALA NAVGUIDE**

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# Introduction

The IMO-led initiave termed e-navigation is a broad church.

Stated simply, the goal of e-navigation is to provide harmonised information in electronic formats, in a seamless, customised and efficient manner, to better-designed navigational systems on board. Ashore, e-navigation aims to streamline the way maritime authorities, agencies and other stakeholders gather and exchange information.

This chapter describes areas of e-navigation development that IALA has been involved in.

# Background

## Origins

In 2006, the International Maritime Organization (IMO) approved a proposal from seven of its Member States, who requested IMO develop an e-navigation strategy.

The aim of the proposal was to *“...develop a strategic vision for the utilization of existing and new navigational tools, in particular electronic tools, in a holistic and systematic manner.”* (MSC 81/23/10). The sponsors of the submission were concerned that if the introduction of new technology remained uncoordinated, it would result in a lack of standardization on board and an increased level of complexity. The proposed e-navigation vision was to create an overarching system that would provide a greater level of safety and incident prevention, resulting in reduced navigation-related accidents.

IMO led other international organisations, notably the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Hydrographic Organization (IHO) and developed a stratgey for the implementation of e-navigation in 2008 (MSC85/26/Add.1 Annex 20). A plan to implement the strategy, termed the Strategy Implementation Plan (SIP), was completed in 2014 (NCSR1/28 Annex 7).

# IMO’s strategy for the development and implementation of e-navigation

## The case for e-navigation

The IMO strategy for e-navigation (MSC 85/26/Add.1 Annex 20) states that about 60% of collisions and groundings are caused by direct human error. Despite advances in bridge resource management training, it seems that the majority of watchkeeping officers make critical decisions for navigation and collision avoidance in isolation. This is partly due to a general reduction in manning.

The strategy also states that in human reliability analysis, the presence of someone checking the decision making process improves reliability by a factor of 10. If e-navigation can assist in improving this aspect, through well-designed onboard systems and closer cooperation with vessel traffic management (VTM) systems ashore, the risk of collisions and grounding (and their inherent liabilities and costs to administrations) can be dramatically reduced.

## Vision

A vision for e-navigation includes the following general expectations for onboard, ashore and communications elements:

**.1 On board**

Navigation systems that benefit from the integration of own ship sensors, supporting information, a standard user interface and a comprehensive system for managing guard zones and alerts. Core elements of such a system will include actively engaging the mariner in the process of navigation, to carry out their duties in the most efficient manner, while preventing distraction and overburdening;

**.2 Ashore**

The management of vessel traffic and related services from ashore, enhanced through better provision, coordination and exchange of comprehensive data in formats that will be more easily understood and utilized by shore-based operators in support of vessel safety and efficiency; and

**.3 Communications**

An infrastructure providing authorized seamless information transfer on board ship, between ships, between ship and shore and between shore authorities and other parties with many related benefits.

## Definition

The IMO stratgey defines e-navigation as 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.”*

In other words, e-navigation means:

* The harmonised exchange and presentation of navigational information in electronic formats.
* Harmonized data exchange and improved communications.
* Creation of a ‘wide area navigation team’, which allows the Officer of the Watch (OOW) and the Vessel Traffic Services (VTS) Operator to share tactical and planning information.
* Improved design of navigational and communication equipment.

## What does the ‘e’ in e-navigation stand for?

It is generally accepted that the IMO concept of e-navigation can be thought of as a brand, without the need for ’e’ to be specifically defined. The concept of e-navigation was first proposed by seven IMO Member States in 2006 as a process for the harmonisation, collection, integration, exchange and presentation of maritime information. As such, the ’e’ could have stood for ’enhanced’ or ’electronic’ (just like the ’e’ in e-commerce), but this would limit what can be done within e-navigation.

It must be noted that the generic term electronic marine navigation already exists in many forms. It should not be confused with this particular IMO initiative.

## Key elements

The key elements of the IMO strategy for e-navigation, based on user needs include:

* Architecture
* Human element
* Conventions and standards
* Position fixing
* Communication technology and information systems
* Electonic Navigational Charts (ENC)
* Equipment standardization, and
* Scalability

According to the strategy, the implementation of e-navigation should be a phased, iterative process of continuous development, taking into account the evolution of user needs and the lessons learned from the previous phase(s).

As part of the basic requirements for the implementation of e-navigation, it was agreed that e-navigation should be based on user needs, not technology-driven.

## e-navigation solutions

The centrepice of the current SIP is the following five prioritized e-navigation solutions:

* S1: improved, harmonized and user-friendly bridge design;
* S2: means for standardized and automated reporting;
* S3: improved reliability, resilience and integrity of bridge equipment and navigation information;
* S4: integration and presentation of available information in graphical displays received via communication equipment; and
* S9: improved Communication of VTS Service Portfolio (not limited to VTS stations).

Solutions S1 and S3 promote the workable and practical use of the information and data on board. Solutions S2, S4 and S9 focus on efficient transfer of marine information and data between all appropriate users (ship-ship, ship-shore, shore-ship and shore-shore).

# IALA’s role

## IALA’s Strategic Vision 2014-2026

The aim of IALA is to foster the safe and efficient movement of vessels through the improvement and harmonisation of marine aids to navigation worldwide. This purpose is given effect by two key goals for 2026.

Goal 1 (G1)

Ensure that aids to navigation systems and related services, including e‐Navigation, Vessel Traffic Services and emerging technologies, are harmonised through international cooperation and the provision of standards.

The strategy for e-navigation is to improve and harmonsie VTS, information structures, Martime Service Portfolios and communications, so as to achieve worldwide interoperability of shore and ship systems.

Goal 2 (G2)

All coastal states have contributed to an efficient global network of aids to navigation and services for the safety of navigation, through capacity building and the sharing of expertise.

Here, the strategy is to coordinate the further development of VTS, e‐navigation and short range aids to navigation, taking into account new technologies and sustainability. Additionally, to continue to develop capacity building activities to improve the global operations and management of aids to navigation systems and related services.

## The e-Navigation Committee

Since 2006, the e-Navigation Committee (ENAV) has led the development of IALA’s substantial contribution to the formulation of the IMO’s e-navigation strategy and the SIP.

There remains a vast amount of work to be done to translate the e-navigation concept into an operational reality. The working groups of the ENAV Committee are engaged in the following technical domains:

* Technical Domain 1: Data modelling and message systems (AtoN data information structure, exchange, presentation, S-100 Registry and Product Specifications)
* Technical Domain 2: e-navigation communications (VDES, satellite, MRCP and AIS technology)
* Technical Domain 3: Shore technical infrastructure (resilient PNT shore services - DGPS, eLoran and virtual AtoN technology)
* Technical Domain 4: e-navigation test beds (gathering and sharing of testbed results)
* Technical Domain 5: Maritime Services Portfolios(design, content and implementation)

Several multi-million dollar projects (completed and underway) have made noteworthy inroads in developing aspects of e-navigation. The IALA e-navigation portal (http://www.iala-aism.org/products-projects/e-navigation) provides detail on known testbeds and their results.

## Answers to Frequently Asked Questions on e-navigation

IALA has developed answers to some Frequently Asked Questions (FAQs) on certain aspects of e-navigation. These can be found on the IALA website.

# Maritime Services Portfolios

The e-navigation SIP states that *”As part of the improved provision of services to vessels through e-navigation, MSPs have been identified as the means of providing electronic information in a harmonized way, which is part of Solution 9.”*

## What are MSPs?

A Maritime Service Portfolio (MSP) defines and describes the set of operational and technical services (and the level of service) provided by a stakeholder in a given sea area, waterway, or port, as appropriate. (NCSR 1/ 28 Annex 7 refers).

As identified by the IMO, there is a need for a harmonised framework for the electronic provision of information related to maritime services between shore and ships. The list of maritime services available at a port, in a region or sea area is structured into services, based on responsible bodies. Such a service is termed a Maritime Service Portfolio or MSP. For instance, “Maritime Safety Information” is one such MSP, with the “National Competent Authority” being the responsible body for the area in question.

Services in a portfolio will vary, depending on the port’s or region’s facilities. For example, a small port may offer only a few services, whereas a large port may offer a greater number of services.

The objective of the MSP concept is to align maritime services globally with the need for information and communication services in a defined operational area. To achieve this, the first step should be to identify the need for information services and communication infrastructure in different areas.

## The sixteen initial MSPs

MSPs are being developed to achieve harmonisation and based on use of the IHO’s S-100 Geospatial Information (GI) Registry.

IALA is developing guidance on the 16 initial services identified by the IMO. These are listed in Table 1 below. It aims to harmonise the format, structure and communication networks that will be used to exchange MSP information. Although the IMO identified the preliminary list of 16 MSPs below (MSC 94/21 Annex 17), these may evolve with time.

|  |  |  |
| --- | --- | --- |
| **MSP Number** | **Services** | **Responsible Service Provider** |
| **1** | VTS Information Service (IS) | VTS Authority |
| **2** | Navigational Assistance Service (NAS) | National Competent VTS Authority/Coastal or Port Authority |
| **3** | Traffic Organization Service (TOS) | National Competent VTS Authority/Coastal or Port Authority |
| **4** | Local port Service (LPS) | Local Port/Harbour Operator |
| **5** | Maritime Safety Information Service (MSI) | National Competent Authority |
| **6** | Pilotage Service | Pilot Authority/ Pilot Organization |
| **7** | Tug Service | Tug Authority |
| **8** | Vessel Shore Reporting | National Competent Authority, Shipowner |
| Operator/Master |
| **9** | Telemedical Assistance Service (TMAS) | National health organization/dedicated health organization |
| **10** | Maritime Assistance Service (MAS) | Coastal/Port Authority/Organization |
| **11** | Nautical Chart Service | National Hydrographic Authority/ Organization |
| **12** | Nautical Publications Service | National Hydrographic Authority/ Organization |
| **13** | Ice Navigation Service | National Competent Authority/Organization |
| **14** | Meteorological information service | National Meteorological Authority/WMO/ Public Institutions |
| **15** | Real time hydrographic and environmental information Service | National Hydrographic and Meteorological Authorities |
| **16** | Search and Rescue (SAR) Service | SAR Authorities |

Table 1: Initial Maritime Service Portfolios (MSPs)

## Technical Services

Based on the concepts of service-oriented architectures, a technical service refers to a set of related software functionalities that can be reused for different purposes, together with policies that govern and control its use. A technical service is a service offered by one electronic device to another electronic device. Often operational services are implemented by electronic devices that rely on one or more technical services.

A technical e-navigation service should be formally specified and documented, as described by an IALA guideline. At the time of writing, this draft guideline aims at improving the visibility and accessibility of available e-navigation technical services and information provided by them. This will enable service providers, consumers and regulatory authorities to have a common understanding of a technical service and its implementation.

# Maritime Digital Infrastructure

Like other industries, the maritime industry has also adopted the use of modern information and communication technologies on board ships and ashore. For example, ships have, for centuries, used paper charts to navigate. These have recently given way to the use of Electronic Chart Display and Information Systems (ECDIS). In the early 2000s, the IMO introduced Automatic Identification Systems (AIS), as one of the first fully digital data exchange systems in the maritime domain, to improve maritime safety. These are but two examples. However, the introduction of new regulations is characteristically slow - major changes take time to be agreed upon and introduced at the international level.

This modernisation of navigation and communication systems, incrementally and over time, has led to ship and shore facilities being fitted with heterogeneous systems. Different technologies and increased information flows can contribute to information overload on ship bridges and shore-based facilities. On the other hand, the integration (and harmonisation of) different systems can offer new opportunities to improve maritime safety and efficiency.

The IMO, by developing the e-navigation strategy (and a plan to implement the strategy) aims to address the above issues by introducing harmonisation and establishing a digital information exchange framework.

From an IALA perspective, harmonisation and digitalisation will have an impact on shore services. For example, a VTS center will be able to use IALA-defined Inter VTS Exchange Format (IVEF) to exchange information with other VTS centers.

## Architectures

The maritime domain is a complex eco-socio-technical system, with many different actors and stakeholders. The international maritime industry is witnessing more and increasingly larger ships being built. Growing ship numbers result in an increase of marine traffic. Therefore, a safe, reliable and environmentally sustainable shipping industry is needed to ensure international trade.

The introduction of new information technologies and their associated system architectures, with increased ability to receive, analyse and present information to optimise a vessel’s passage, is changing international shipping. These systems do more than enhance safety and security in the shipping domain. For example: traffic management and port call optimisation technologies are interwoven into other domains such as transport logistics.

The evolution of technology and its data requirements leads to an increased need for maritime systems with bandwidth demands, such as broadband connections on the high seas. Additionally, the growing number of new developments in the shipping industry results in a large and diverse number of maritime systems.

These complex Information and Communications Technology (ICT) systems need an architecture to address organisational and technical aspects and to ensure alignment with regulations, governance and operational processes.

The Maritime Architecture Framework (MAF) is introduced below, to provide a common platform for the design of maritime architectures. The Common Shore-based System Architecture (CSSA) is introduced as a blueprint for a specific architecture.

### Maritime Architecture Framework (MAF)

The Maritime Architecture Framework is an architecture framework for maritime eco-socio-technical system-of-systems (SoS). It provides a methodology to structure the specification of architectures in a common way, and furthermore provides an architecture model to enable the representation of the architecture in a maritime SoS context. The MAF orients towards the e-navigation and other related approaches such as e-maritime.

Current technology innovations in the maritime domain allow for a holistic approach to guide common engineering processes among (new) maritime systems, and their field of activities in the operational context – state more simply. Therefore, it is essential to establish a standardised methodology to analyse, design, compare and discuss different maritime IT-architectures and socio-technical systems, including related regulations within their (envisioned) maritime context, in a consistent and harmonised way.

Therefore, the MAF take IMO’s e-navigation approach into account to provide a methodology and architecture model to compare maritime systems with each other, and to identify overlaps or gaps on different interoperability levels in order to support the implementation process of new e-navigation approaches. Furthermore, it contributes to the necessity of setting new e-navigation approaches in a broader context within the current state of the maritime domain and the e-navigation strategy (and relatives) (see Figure 1 below).

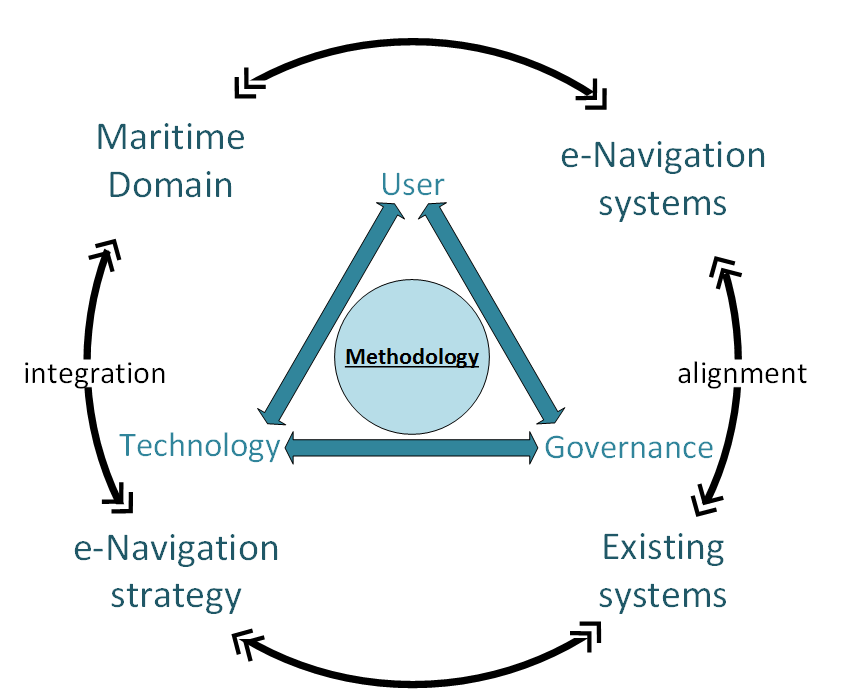


Figure 1: Contextualisation of e-navigation in the maritime domain

The Maritime Architecture Framework faces the challenge of bringing the maritime domain, with its manifold and divergent aspects, into an order. It also encapsulates different views on architectures, with the goal of ensuring a comprehensive architecture description of a system. It is based on enterprise architecture-engineering methods and supports the harmonisation of systems from relevant perspectives: Conceptual, Organisational and Technical.



Figure 2: The structure of the Maritime Architecture Framework

As seen in Figure 2, the framework exists of a set of elements arranged around, and integrated into, a system design methodology. This methodology is for the specification of socio-technical system architectures and its maritime SoS environment and follows an iterative approach.

The Structural Framework element is a multidimensional architecture model for the allocation and representation of system architectures in the maritime and interoperability context.

The Requirements Management and Analysis elements provide methods and processes for continuous requirements management during the specification, as well as for multiple kinds of analyses on reflected system architectures. The optional (\*) design rules element, is intended for the definition of a set of rules concerning the inherent structure of a defining system architecture, with the goal to establish a template for how the system elements need to be arranged.

All elements of the MAF contribute to the real maritime environment, its systems and technologies and towards design and reference architecture that stem from engineering principles.

Therefore, during the application of the MAF, a common terminology shall be considered by its users and existing maritime systems and technologies. Furthermore, if used for the definition of new system architectures and their integration into the maritime environment, the IMO’s Maritime Service Portfolios and the maritime environment is relevant. There are design principles from a broad field of system engineering which affect the building of systems. Finally, non-governmental organizations, such as IALA, should recommend reference architectures such as the CSSA (Common Shore-based System Architecture, as described below), which must be reflected within the design of system architectures.

#### The multidimensional model of the MAF (The Structural Framework)

The MAF integrates within its methodology a multidimensional model approach. This enables the visualisation of those architecture aspects in a “cube” for an easy identification of interoperability issues, gaps and overlaps between the mapped system components. This establishes clear relationships between:

* existing business objectives,
* governmental aspects, which regulates the maritime domain,
* technical functions, that are required to realise the business objectives,
* information exchange between those technical functions, including the related information types and/or data models,
* communication protocols to allow the aspired information exchange, and
* components required to implement the technical hardware.

The benefits of having these are various: Firstly, it supports optimal alignment of technical systems with organisational concepts. This integrated view is required to ensure technical and organisational interoperability. Secondly, it supports the potential integration of systems into a system environment by providing a model for the combined mapping of multiple Systems components. A component can be for instance a constituent system itself (System of Systems, SoS).

The model consists of a three-dimensional structure of architectural aspects assembled in a meaningful way. It is structured in layers to “cut” the cube at each category along each dimension. Therefore, the terminology “axis” is used for the name of the dimension, and “layer” for the surface with all aspects which belong to a category. All aspects on a layer can be sub-structured by the categories of other dimensions.

With regards to the IMO’s e-navigation architecture and its definition, the cube covers interoperability aspects to support different views on the interaction of maritime systems. Furthermore, it features the distinction between ship-side and shore-side and breaks down the structure of management and control systems in the maritime domain into a hierarchical order.

The model represents characteristics of the maritime domain using the three dimensions, *Interoperability axis*, *Topological axis* and *Hierarchical axis* (see Figure 3 below). The different axes of the multidimensional model are further described below.

|  |
| --- |
| cube    Figure 3: The multidimensional model of the MAF |

**Hierarchical axis**

The *Hierarchical axis* brings the maritime domain into an order. The layers of this hierarchy reflect the structure and aggregation of the organisational aspects (management) and control systems in the maritime domain. The dimension categories cover economic and governmental aspects (fields of activity), operation control parts of maritime systems (*Operations*), the technical (*Systems, Technical Services, Sensors and actuators*) as well as physical components (*Transport objects*). Each layer addresses both technical and human aspects.

* *Fields of activity*: Systems which support or manage different markets or eco systems along the maritime domain.
* *Operations*: Global, regional, national and local operational perspectives used by companies or authorities (e.g. a traffic flow management).
* *Systems*: Technical systems which integrate or use technical services for gaining a virtual representation and control of the transport processes.
* *Technical Services*: Single technical and logical services.
* *Sensors & actuators*: Local infrastructure for detecting objects with physical means, and receiving and processing the results with physical systems and hardware.
* *Transport objects*: Entities of maritime transport processes such as vessels, floating objects and aircrafts operating in the maritime domain.

These layers help to understand the definition and role of operational services, as for instance described in the Maritime Service Portfolio (MSP). This includes their provision by technical systems providing technical services.

**Topologicalaxis**

The *Structural Framework* covers the elements and its interrelationship of the maritime domain. It reflects the maritime structure from a topological perspective as defined in IMO’s e-navigation architecture. This axis is sub-structured into the following categories:

* *Ships and other maritime traffic objects*: Representing entities in the maritime domain (e.g., vessels). It covers the ship-side entities of the e-navigation architecture.
* *Link*: Representing entities dedicated to physically interact between maritime traffic objects and shore, such as telecommunication methods and protocols. Represents the three levels of Operational links, Functional links and Physical Links between ship-side and shore-side.
* *Shore*: Representing entities of the shore side infrastructure, activities and systems on shore including interfaces to logistical movements in/out of the maritime domain.

**Interoperability axis**

The interoperability layers cover organisational, informational and technical aspects and include the different levels of interaction (operational, functional, technical and physical) as stated in the IMO’s e-navigation vision. This axis is sub-divided into the following categories:

* *Regulation & governance:* Role and legal basis of international, regional or national (shipping) authorities.
* *Function*: Functions and (elemental) services including their relationships.
* *Information*: Data and information that is being used and exchanged between functions, services and components. It describes data and information objects including its semantic and data models.
* *Communication*: Protocols and mechanisms for the interoperable exchange of data between components.
* *Component*: Required components in engineering terms. This includes, amongst others: systems, actors, applications, services and network infrastructure.

### IMO Architecture

As mentioned previously, the IMO has identified a generic architecture for e-navigation. One way of understanding the concept of e-navigation is to consider it from a user’s perspective. In Figure 4 below, the architecture can be divided into three parts; ship-side, shore side and the interaction between ship and shore.

The ship-side represents the users on-board a ship, whilst the shore side typically represents users from communities like VTS, allied services and users from the logistics domain.

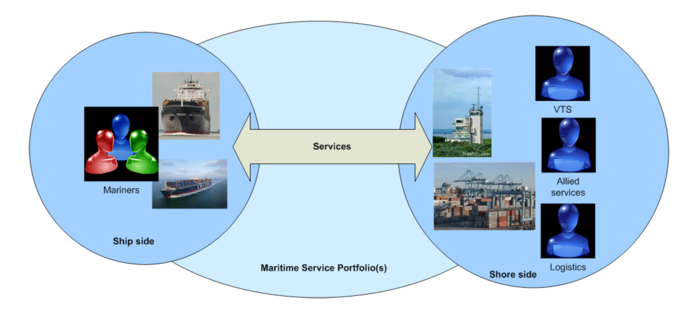
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_4-5-3_Figure19_eNavigation_User_Perspective_at_a_Given_Moment_and_Given_Place.png)

Figure 4: e-navigation users' perspective at a given moment and place

To enable both sides to communicate and exchange information, e-navigation uses the generic term “service”. From a user’s perspective, the important services will be the “operational services”. These services are referred to within a Maritime Service Portfolio (MSP). The MSP concept was conceived to achieve harmonisation. However, there also needs to be “technical services” to be able to support and provide these operational services (see Figure 5 below).

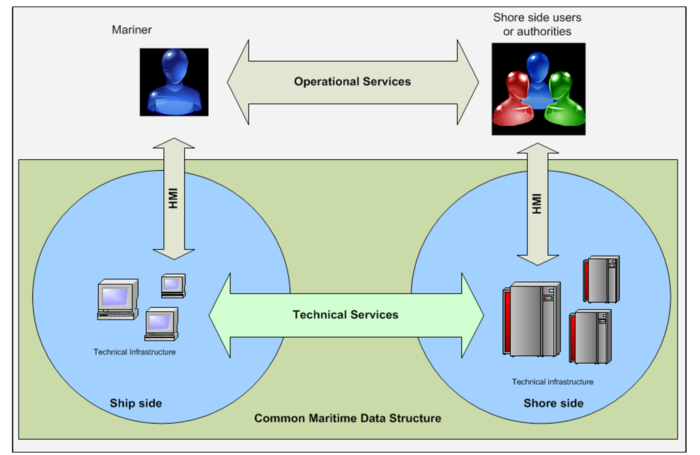
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_4-5-3_Figure20_The_eNavigation_Services_Concept.png)

Figure 5: The e-navigation services concept

These base concepts are detailed in the overarching e-navigation architecture, which is defined in the IMO e-navigation Strategic Implementation Plan (SIP).

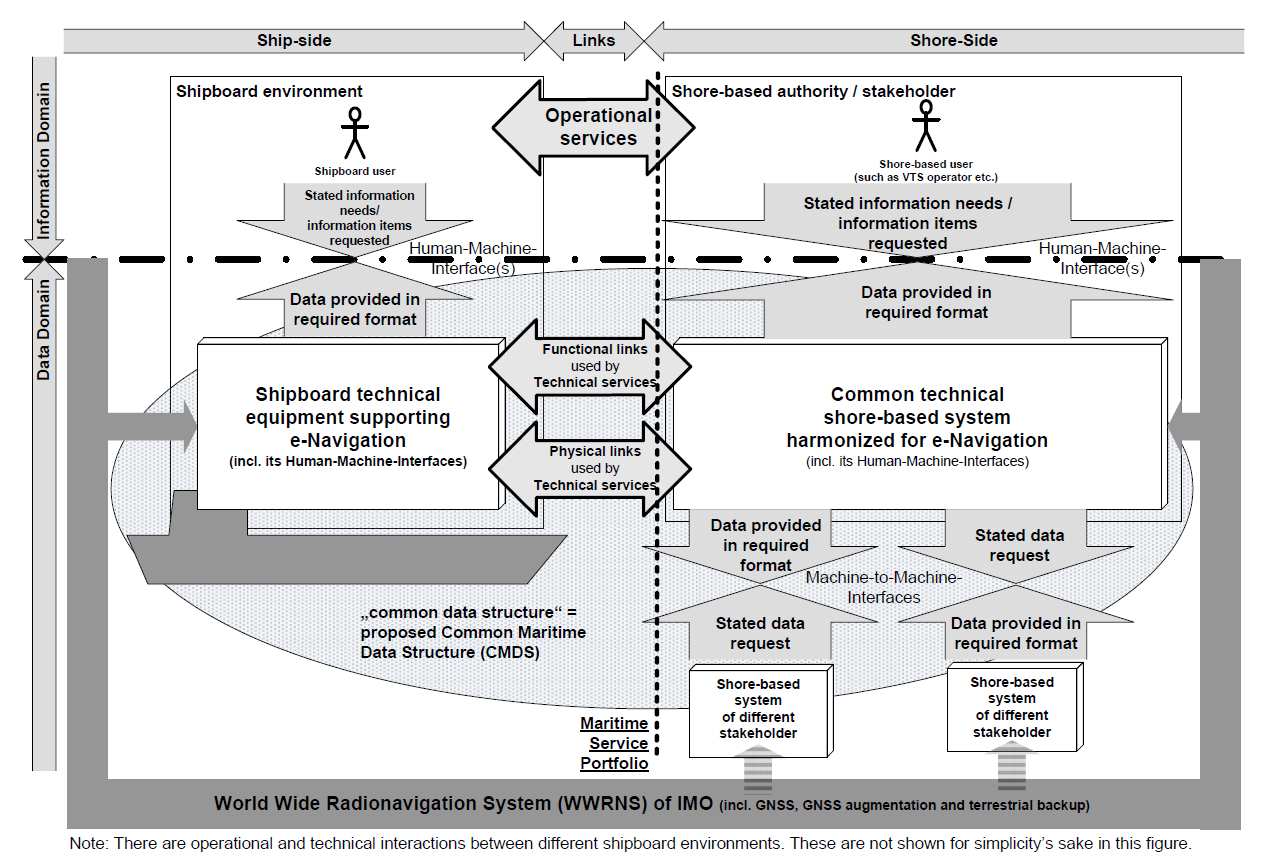


Figure 6: IMO e-navigation architecture

Figure 6 shows the most important features and elements. These are:

1. the distinction between the ship and shore-sides;
2. the distinction between the information and data domains;
3. the notion of request/fulfilment relationships throughout;
4. the technical Human Machine Interfaces (HMIs);
5. the notion of operational and technical services provided to shipping, as defined by Maritime Service Portfolio(s) (MSPs);
6. the ‘shipboard technical equipment supporting e-navigation’;
7. the ‘common shore-based technical system harmonised for e-navigation’;
8. the overarching role of the Common Maritime Data Structure (CMDS) within the data domain;
9. the shore-to-shore data exchange facilities, and the required Machine-to-Machine (M2M) interfaces, and
10. the dependency on the World Wide Radio Navigation System (WWRNS).

### Common Shore-based System Architecture (CSSA)

IALA Guidelines 1113 (Design and Implementation Principles for Harmonised System Architectures of Shore-based Infrastructure) and 1114 (A Technical Specification for the Common Shore-based System Architecture (CSSA)) identify the principles of a shore-based system architecture and propose its technical specification. As stated earlier, there are three major components of the e-navigation architecture that interact with each other. They are:

1. Shipboard systems that process information/data;
2. Application-to-application data exchange via physical links;
3. Shore-based systems that integrate a variety of shore based technologies and data processing devices.

The CSSA describes the technical set-up of the shore-based system of a shore authority. The main building block of the CSSA is the technical service, which encapsulates all primary functions dealing with a specific technology or user, depending on the kind of technical service. To reap the maximum benefit, all technical services of the CSSA should adhere to the same object-oriented engineering model. All technical services are self-contained and provide all capabilities needed for their tasks, including their own service management.

The CSSA is modelled in a client-server-fashion. The individual technical services can regularly assume either role, i.e. clients or server, depending on their present role in a given interaction chain, in support of a given application-to-application data exchange within the overarching architecture.

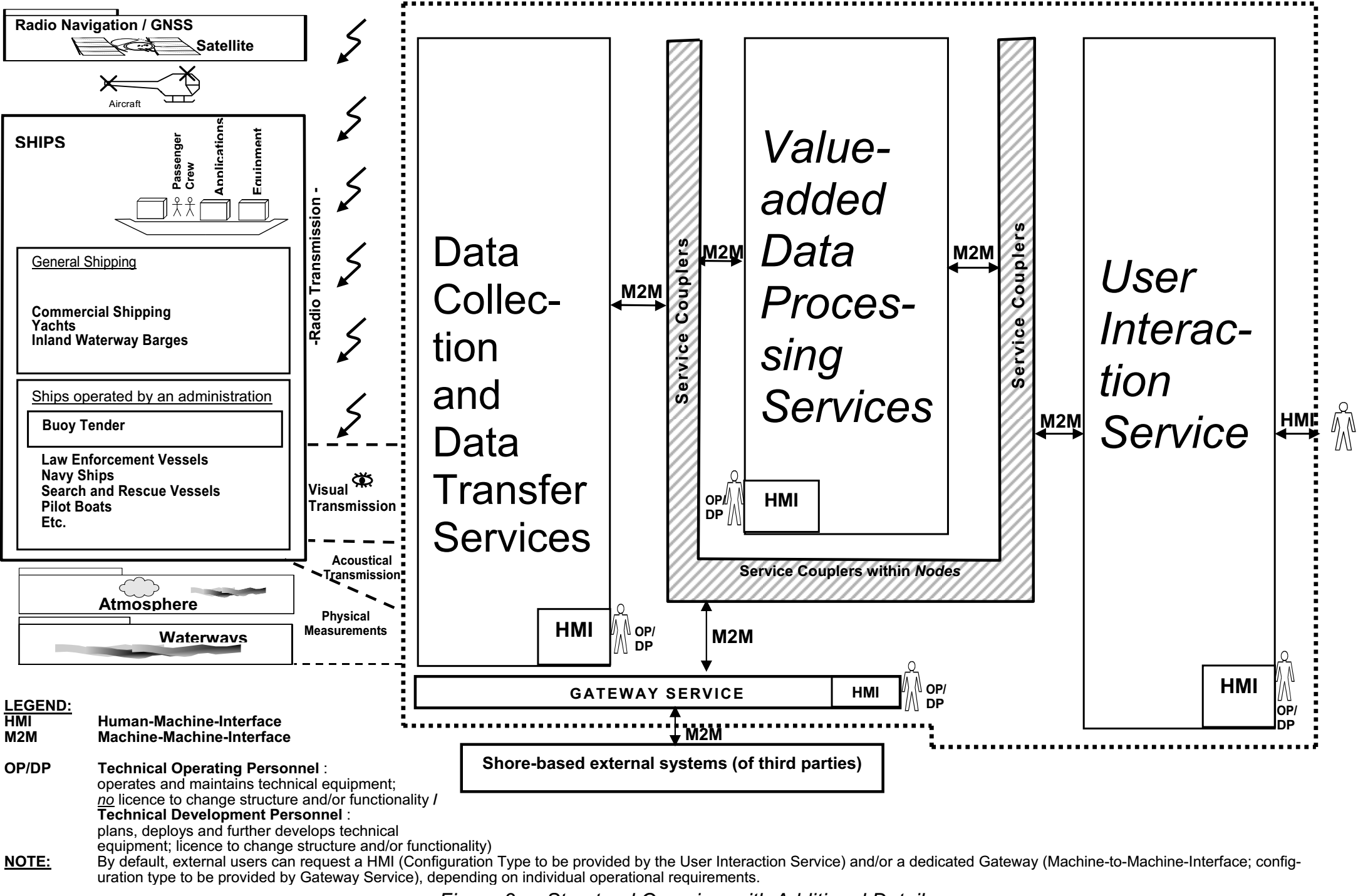


Figure 7: The Common Shore-based System Architecture concept

Figure 7 provides the main concepts of the CSSA:

* Data collection and transfer services are a group of technical services interfacing the shore system, via physical links to the electronic systems of traffic objects’, to the waterways and to the natural environment.
* Value added data processing services are also a group of individual technical services. Their main task is to add value to (raw) data by processing, combining, comparison etc., store data and information and to provide it upon request to other technical services.
* The user interaction service – an individual technical service – is specialised to provide the Human-Machine-Interface (HMI) to the primary users of the CSSA, i.e. such users as are supported directly by the system via dedicated displays, keyboards and other human interaction devices.
* The gateway service – another individual technical service – specialises in shore-to-shore data exchange. It interfaces mainly to the external systems of third parties. Upon authorised request, external systems provide data to and/or receive access to relevant data from own system. The Gateway Service can also interface different shore-based systems locally, regionally, and globally.

Examples of data collection and data transfer services are AIS, radar services, direction-finding services and DGNSS augmentation services. Some value added data processing services are position determination services, ship data consistence algorithms and data mining services.

## Common Maritime Data Structure

The purpose of the IMO-defined Common Maritime Data Structure or CMDS (see Figure 8) is to harmonise data exchange in the maritime domain, by providing a common, authoritative reference. The CMDS is an abstract representation of entities within the maritime domain. It should be accessible by any stakeholder and should be the reference for the development of maritime services, applications and databases.

Considering the extent of the maritime domain with all of its stakeholders, the responsibility for the CMDS is subdivided into smaller units, each of which is governed by a recognised authority. However, these authorities need to cooperate to harmonise the CMDS as a whole (e.g. to avoid duplication of entries). This is one of the main tasks of the IMO established IMO/IHO Harmonisation Group on Data Modelling (HGDM).

IHO developed the IHO GI Registry [1], S-100 provides the data framework for the development of the next generation of ENC products, as well as other related digital products required by the hydrographic, maritime and GIS communities. The GI Registry is generic in setup and has been adopted by IMO to support development of the CMDS.

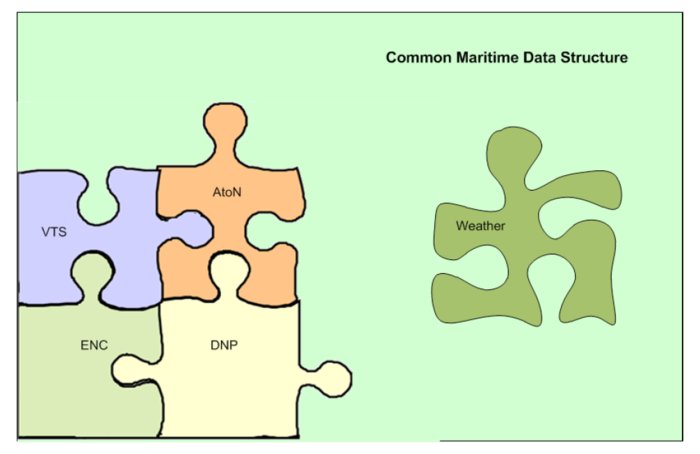
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_4-5-4_Figure21_The_Harmonised_Common_Maritime_Data_Structure.png)

Figure 8: The Harmonised Common Maritime Data Structure

Figure 8 describes the simplified generic structure of the GI Registry. The major features of the registry include registers for:

* Product Specifications – includes everything needed to fully describe and specify a ‘product’, such as data exchange protocols and references to HMI and CMDS entities from the GI Registry.
* Human-Machine Interface (HMI) – HMI definitions/specifications can also include references to CMDS entities from the GI Registry. (This register is named Portrayal by IHO).

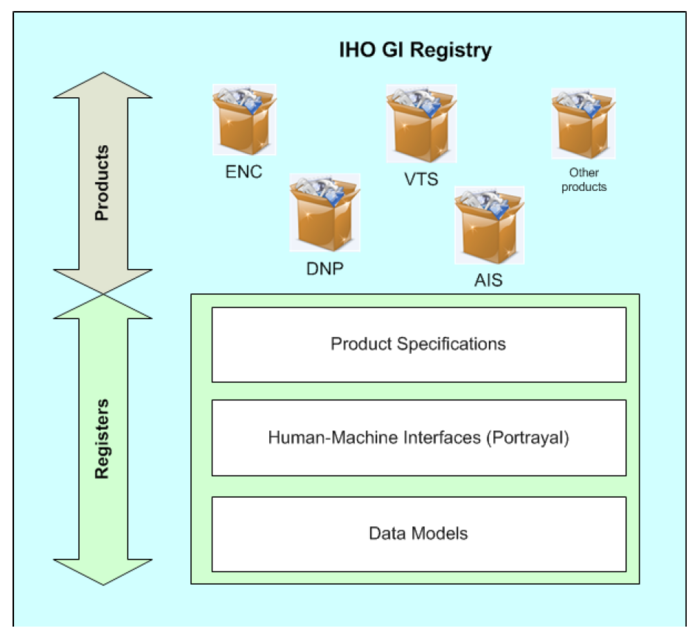
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_4-5-4_Figure22_Simplified_View_of_the_IHO_GI_Registry.png)

Figure 9: Simplified View of the IHO GI Registry

## Common Maritime Infrastructure

In order to facilitate the integration of e-navigation into the maritime domain, shared and broadly available infrastructure is needed. GMDSS and its services are good examples for such a critical infrastructure. New technological developments and their deployment, like better satellite bandwidth and terrestrial mobile data services, will foster Internet based technologies in this global system.

In order to provide such infrastructures and interoperability between used technologies, the introduction of common approaches for identity management or Maritime Resource Name (MRN) are necessary.

### Identity Management

The notion of identity is vital for all information exchange and communication technologies. Just as human-to-human communication on a global scale would be impossible without unique telephone numbers/email addresses, so too is a globally agreed digital maritime identity required for the various participating ‘actors’.

In the maritime sector, there are already many identity systems in place (e.g. IMO number, MMSI). These are managed by different organisations.

The challenge in creating a single maritime identity regime is to create a solution that satisfies the most common identification needs of the entire maritime industry, on a global scale, while also being compatible with already established identity systems. A key task is to establish authentication between maritime users.

The way in which a human user or machine may be authenticated typically falls into three different categories, based on what is commonly known as the factors of authentication: something the user knows, something the user has and something the user is. Each authentication factor covers a range of elements used to authenticate or verify a person's identity prior to being granted access, approving a transaction request, signing a document or other work product, granting authority to others and establishing a chain of authority.

* Knowledge factors: passwords, pass phrases, pins, challenge / response
* Ownership factors: ID card, cell phone, certificates
* Inheritance factors: Fingerprint, retinal patterns, facial and voice recognition

Emerging approaches, such as the Maritime Communication Platform, address the identity issues.

### Maritime Resource Name (MRN)

In order to assist with the implementation of the Common Maritime Data Structure (CMDS), IALA has proposed the concept of Maritime Resource Name (MRN).

IALA has developed a draft guideline on Unique Identifiers for Maritime Resources, introducing the concept of a MRN as a means for the creation of globally unique identifiers. The MRN is a Universal Resource Name (URN) scheme that makes national AtoN numbers globally unique by applying a (national) prefix. In addition to AtoN numbers, the larger scale use of unique identifiers is necessary for e-navigation, for harmonisation across domains and services. Navigationally unique objects such as AtoN, VTS products and services and other maritime resources require identification to avoid duplication and misalignment.

As of 2017, IALA is working with authorities such as the Internet Assigned Numbers Authority (IANA) to pursue the registration of MRNs.

### Maritime Connectivity Platform

The Maritime Connectivity Platform (MCP) (formerly known as Maritime Cloud) is an emerging concept for a proposed communication framework that will enable efficient, secure and reliable electronic information exchange between authorised stakeholders. Basically, it defines the standards, protocols, infrastructure and governance for information exchange based on the Service Oriented Architecture concept. It is not a storage cloud – nor is it cloud computing. Neither does it provide a communications infrastructure. The MCP will make use of new communication platforms and provide a standardised use concept.

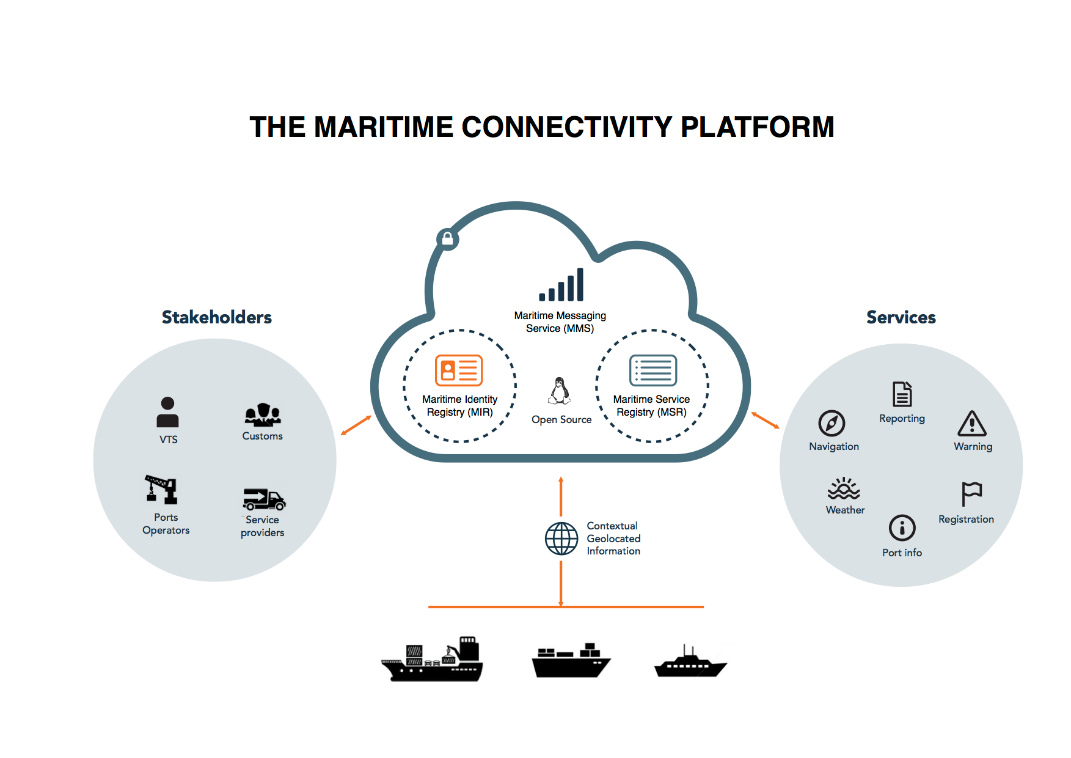


Figure 10: *The Maritime Connectivity Platform concept*

*(Image courtesy: EfficienSea Project)*

The MCP is structured such that:

* Communications is based on the client-server concept;
* Services can be easily registered, discovered and used;
* Identities can be verified and used to digitally sign communication; and
* Messages can be exchanged between components connected to the cloud. These can be either clients operated by humans or services.

Geographic and organisational contexts (e.g., a vessel’s location) are used as key parameters for service discovery, identity verification and message exchange.

The MCP offers a Service Registry. Components connected to the cloud ‘ask’ the service registry how to access and use a service. Additionally, the MCP provides a Maritime Messaging Service (MMS). This component can be thought of as an automated switchboard. It uses the communication channel available for communication to a service while the access point (the "telephone") stays the same. Depending on the request (name, type, location etc.), the end user is provided with possible service providers, and can then choose which service to use.

The MCP offers means to digitally assure the identity of the communicating partners (thereby doing away with the need for signed documents to prove authenticity).

The MCP does not include data storage or application hosting. This remains the responsibility of service providers and organisations. The MCP is focused on improving communication and digital interactions based on open standards, while reusing existing components and infrastructure within the current organisations to enable a cost-effective and smooth transition to adoption.

## Cyber Security

Digitalisation in the maritime industry presents new threats such as systems failures and cyber security. AIS, GNSS and GMDSS provide no protection against cyber-attacks. They can be attacked very easily, with little financial or technical effort. The only resilience against cyber-attacks is the redundancy of systems. AIS is an unencrypted system operating in the VHF maritime mobile band; positioning technologies use resilient systems to overcome vulnerability. However, the risk of concentrated actions, which can lead to system failures, is ever-present.

As technology continues to evolve, information technology and operational technology onboard ships are increasingly being connected – to each other and to the world wide web. This gives rise to greater risk of unauthorised access or malicious attacks to ships’ systems and networks. Risks may also occur from personnel having access to the systems onboard, for example, by introducing malware via removable media.

Responding to the increased cyber threats, BIMCO undertook a comprehensive analysis of cyber security related threats and risks and produced *Guidelines on Cyber Security onboard Ships* in 2017. These guidelines are designed to assist companies develop resilient approaches to cyber security onboard ships.

Relevant personnel should be trained to identify some typical modus operandi of cyber-attacks. The safety, environmental and commercial consequences of not being prepared for a cyber incident may be significant.

Approaches to cyber security will be company and ship specific, but should be guided by appropriate standards and the requirements of relevant national regulations.

# Communications

## Introduction

The e-navigation concept aims to enhance the efficiency, safety and security of navigation and communications in the maritime sector. e-Navigation relies on applications which provide mariners with the information they need in a more secure and efficient manner. These applications require communication technologies that can provide the necessary capability for ship-ship and ship-shore (including ship-satellite) communication.

The role of communications as a cornerstone in safety at sea was highlighted by the sinking of *Titanic* in 1912. The two radio operators, Jack Philips and Harold Bride, transmitted the first SOS message, which resulted in the rescue of some 700 persons. Effective and efficient radiocommunications at sea are vital for the safety of life, protection of the environment, efficiency of ship movements and maritime Search and Rescue (SAR).

The nine GMDSS functional requirements cover not only distress alerts and SAR communications, but Maritime Safety Information (MSI), general radiocommunications and bridge-to-bridge communications as well. The four levels of priority in radiocommunications are described in the ITU Radio Regulations. They are distress, urgency, safety and other communications.

## Digital Communications

Digital communications are now an integral part of our daily lives – be it for work, social interaction or recreation. The introduction (and expectation) of ‘anytime, anywhere’ access to up-to-date information via the internet, text and image-rich communications, geospatial locating and more, are driving demand for faster, more robust, and more integrated communication solutions.

Almost every e-navigation solution currently being developed (and foreseen) depends upon efficient and robust ship-ship, ship-shore or shore-ship electronic data transfer. Existing communications systems may in many places be adequate to serve these needs. However, it is necessary to develop new methods to realise the full potential of e-navigation. The performance requirements, in particular data capacity, for communications systems to support e-navigation are, in many cases, unknown and are likely to change over time. However, studies and user requirement workshops have been conducted to better determine the data transfer requirements, to address e-navigation elements and facilitate development of digital communications solutions for the maritime environment.

Development of robust and reliable communications infrastructure is not only related to the implementation strategy for e-navigation, but is also a core element of the modernisation of GMDSS.

Work on maritime communications not only looks at more effective use of existing systems, but also developments in digital communications. Some of the technologies for future digital maritime communications include:

* NAVDAT: This system is an enhancement of the current NAVTEX system. The service will support the same major functions as NAVTEX, namely navigational warnings, weather forecasts and emergency information for shipping, but will provide a much greater capacity and data rate.
* VHF Data Exchange System: VDES was developed to meet the increasing need for data communication between maritime users, and was driven by the increasing use of AIS resulting in a significant rise in load on the VHF Data Link. VDES provides faster data transfer rates with greater integrity than current VHF data link systems.
* Digital Selective Calling: DSC transmits packets of data over existing maritime radio spectrum, on VHF, MF and HF. The system uses Maritime Mobile Service Identity (MMSI) and enables direct transmission or group/area transmissions of basic data. DSC is included in the Global Maritime Distress and Safety System (GMDSS) as a distress sand calling mechanism.
* Digital VHF: Digital VHF is the evolution of analogue-based mobile radio systems currently used by mariners for voice communication, transmission/reception of distress and safety information and reception of urgent marine information broadcasts. As well as digitally encoding voice transmissions, digital VHF will enable the exchange of data messages. This may be a longer term development.
* Digital HF: Digital HF is the evolution of analogue-based mobile radio systems currently used by mariners for voice communication, transmission/reception of distress and safety information, and reception of urgent marine information broadcasts. As well as digitally encoding voice transmissions, digital HF will enable the exchange of data messages. Digital HF, including standards for digital HF, exist, but are not commonly used.
* Wi-Fi: provides local area wireless data transfer using the 2.4 GHz to 5 GHz radio wave band. However, the coverage of this system is limited to small areas within a port or harbour environment.
* 4G: a mobile telecommunications standard supporting mobile internet broadband, succeeding 3G. Provides mobile broadband with data rates of 100 Mbps for mobile users. Systems that perform to the 4G standard include WiMAX and LTE. LTE developments include LTE-Advanced, which will provide greater range.
* 5G: The Long Term Evolution (LTE) planned for 4G, with data rates expected to be 1 Gbps and intended for availability in the year 2020.
* Satellite communication systems and services including, but not limited to:

1. Inmarsat Global Xpress - GEO satellite constellation. The latest set of services to be offered by Inmarsat, including shared channel IP packet-switched internet broadband service with fast data rates provided by satellites in the Kaband with global coverage.
2. Inmarsat C - GEO satellite constellation. Existing short burst data, store and forward system, providing low data rates for small message size transfers and also supporting the Global Maritime Distress and Safety System (GMDSS).
3. Iridium - LEO satellite constellation. Existing low-earth orbiting communications system, providing voice and limited internet access.

In 2009, IALA developed a Maritime Radio Communications Plan (MRCP) for the communications required to support e-navigation. The MRCP has been updated in 2017. It can be found at <http://www.iala-aism.org/product-category/publications/other-publications/>

The MRCP is intended to meet the key e-navigation strategy element of identifying communications technology and information systems to meet user needs. This can involve the enhancement of existing systems and the development of new systems. The IALA plan identifies existing and future systems, then draws on identified user requirements to assess the information flows and the data channels needed.

## VHF Data Exchange System

### Overview

The Automatic Identification System (AIS) provides an effective means to transfer digital data. In addition to the originally-intended purpose of providing vessel position and related information to aid in collision avoidance, support VTS operations and contribute to the safety of navigation, AIS is being used for a number of other applications. This has seen an overloading of the VHF data link in some areas.

At the World Radio Conference 2015, the International Telecommunications Union identified an additional 6 duplex channels in the VHF maritime mobile band for the use of digital data transfer. The frequencies form part of the developing VHF Data Exchange System (VDES). With the ability to group these frequencies together to provide more bandwidth for data transfer, the VDES will enhance digital data functionality in the future.

VDES provides a solution to ensure that the existing AIS VHF data link does not become overloaded. VDES is made possible by the development of software definable radios (SDRs) and the frequency allocation in addition to the existing AIS within the system. VDES includes VHF Data Exchange (VDE) and Application Specific Messages (ASM). The VDE includes an agreed Terrestrial element (VDE-T) as well as a developing Satellite element (VDE-S). The satellite component of VDES will ensure global communication capability including the polar-regions. VDE-S is under development, with studies to be provided to the World Radio Conference in 2019. VDES is seen as an effective and efficient use of radio spectrum, building on the capabilities of AIS and addressing the increasing requirements for data through the system. VDES will include AIS as it currently exists. It will also include new techniques that provide higher throughput using multiple channels which can:

* be merged to provide higher data rates; and
* provide simultaneous message diversity from multiple sources.

Furthermore, the VDES network protocol is optimized for data communication. The objective is that each VDES message is transmitted with a high degree of confidence of reception.

The VDES should improve the safety of life at sea, the safety and efficiency of navigation, the protection of the marine environment and enhance maritime safety and security. These goals will be achieved through efficient and effective use of maritime radiocommunications, incorporating the following functional requirements:

1. As a means of AIS.
2. As a means of radiocommunications equipment through exchange of digital data between ship and ship, ship and shore including satellite via AIS, Application Specific Messages (ASM) and VHF Data Exchange (VDE).
3. As a means of applications external to the VDES equipment itself. These applications use AIS, ASM or VDE separately or combined.

Implementation of VDES has commenced, building on the allocation of spectrum at WRC-15 where the ITU approved a standard for VDES (Recommendation ITU-R M.2092-0). A remaining issue is the approval of the satellite component for the VDE channels which is targeted for approval at WRC-19.

The system concept including VDES functions and frequency usage are illustrated pictorially in Figure 11 (entire system, including satellite allocations).

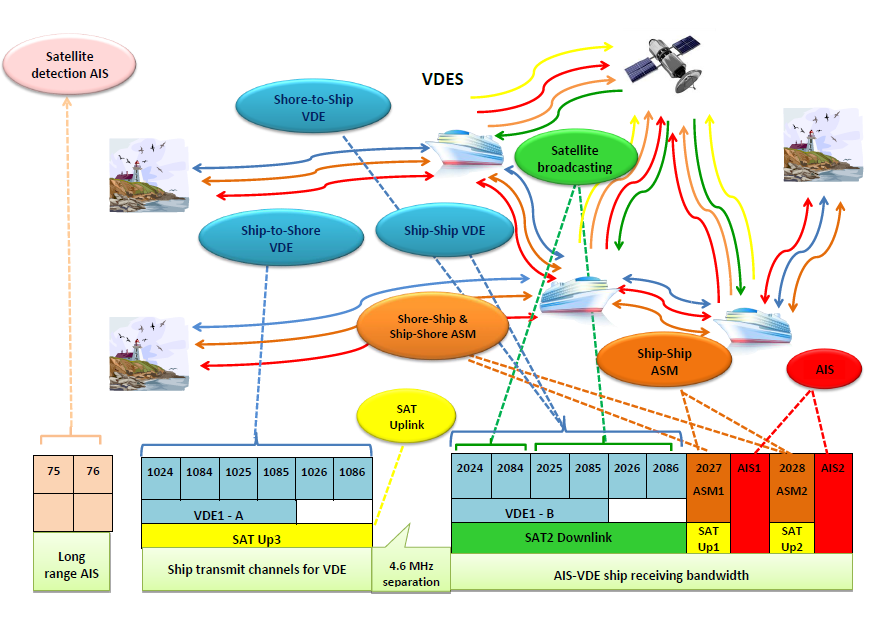


Figure 11: VDES functions and frequency use – a view of the entire system

| Channel number in RR Appendix 18 | Transmitting frequencies (MHz) for ship and coast stations | |
| --- | --- | --- |
| Ship stations (ship-to-shore)  (long range AIS)  Ship stations (ship-to-satellite) | Coast stations  Ship stations (ship-to-ship)  Satellite-to-ship |
| AIS 1 (was 87B) | 161.975 | 161.975 |
| AIS 2 (was 88B) | 162.025 | 162.025 |
| 75 (long range AIS) | 156.775 (ships are Tx only) | N/A |
| 76 (long range AIS) | 156.825 (ships are Tx only) | N/A |
| 2027 (ASM 1) | 161.950 (2027) (SAT Up1) | 161.950 (2027) (SAT Up1) |
| 2028 (ASM 2) | 162.000 (2028) (SAT Up2) | 162.000 (2028) (SAT Up2) |
| 24/84/25/85 (VDE 1)  24  84  25  85 | 100 kHz channel  (24/84/25/85 lower legs merged)  Ship-to-shore  Ship-to-satellite (SAT Up 3) | 100 kHz channel  (24/84/25/85 upper legs merged)  Ship-to-ship, Shore-to-ship  Satellite-to-ship under certain conditions (SAT2 possible extension) |
| 157.200 (1024) | 161.800 (2024) |
| 157.225 (1084) | 161.825 (2084) |
| 157.250 (1025) | 161.850 (2025) |
| 157.275 (1085) | 161.875 (2085) |
| 26/86  26  86 | 50 kHz channel  (26/86 lower legs merged) VDE 2  Ship-to-satellite (SAT Up3) | 50 kHz channel  (26/86 upper legs merged)  Satellite-to-ship (SAT 1) |
| 157.300 (1026) VDE 2, SAT Up3 | 161.900 (2026) (SAT 1) |
| 157.325 (1086) VDE 2, SAT Up3 | 161.925 (2086) (SAT 1) |
| 80/21/81/22 | 100 kHz channel  (80/21/81/22 lower legs merged)  Ship-to-shore (VDE-T) | 100 kHz channel  (80/21/81/22 upper legs merged)  Shore-to-ship (VDE-T) |
| 80 | 157.025 | 161.625 |
| 21 | 157.050 | 161.650 |
| 81 | 157.075 | 161.675 |
| 22 | 157.100 | 161.700 |
| 82 | 157.125  Ship-to-shore (VDE-T) | 161.725  Shor-to-ship (VDE-T) |
| 23/83 | 50 kHz channel  (23/83 lower legs merged)  Ship-to-shore (VDE-T) | 50 kHz channel  (23/83 upper legs merged)  Shore-to-ship (VDE-T) |
| 23 | 157.150 (VDE-T) | 161.750 (VDE-T) |
| 83 | 157.175 (VDE-T) | 161.775 (VDE-T) |

Table 2: VDES Channel allocation

IALA has published a guideline that provides an overview of VDES, including the road map to develop and implement this system.

### AIS

The issue of correlating a ship’s identity and its position in coastal waters and port approaches had been frustrating shore authorities for some time. It was long realised that an automatic reporting device fitted to vessels would mitigate this problem. It would contribute greatly to the safety of navigation and traffic management by exchanging information such as identity, position, time, course and speed between ship and shore regularly, automatically and autonomously.

Vessel Traffic Services (VTS) and ports have a requirement for clear and unambiguous identification of vessels within their area, while the ability to provide such information ship-ship was identified as a benefit for safety of navigation and collision avoidance.

Separately, the maritime community was developing the technology and rules for a VHF radio system which would enable ships to automatically communicate data with each other for the purpose of safe and efficient navigation. This was the Universal Automatic Identification System, now known as just AIS.

It quickly became clear to shore authorities that AIS also had the potential to support a wide range of maritime regulatory and traffic monitoring activities and assist with maritime security. These include:

* ship operations;
* vessel tracking;
* investigations and prosecutions;
* search and rescue;
* environment protection;
* port State control;
* casualty management;
* compliance with pilotage requirements;
* vessel traffic services;
* planning of navigational services (e.g. ships’ routeing measures);
* monitoring of (and use as) aids to navigation; and
* strategic planning.

AIS is a critical element of VDES as a system. Overview information on AIS can be found in IALA Guideline 1082 (An overview of AIS). This and numerous other IALA guidance documents are available at the Publications area of the IALA website (<http://www.iala-aism.org/product-category/publications/>). There are also a number of AIS reference documents published by the IMO, ITU and IEC.

#### Satellite AIS

Terrestrial AIS systems have the benefit of continuous coverage and detection rates that approach 100% close to shore. Terrestrial AIS includes both receive and transmit capabilities, although many shore stations (AIS base stations) may be capable of only receiving AIS information. Terrestrial AIS, however, has the disadvantage of limited range and relatively high cost per square mile covered.

Satellite AIS (S-AIS) is a receive-only system, but has the advantage of providing complete global coverage with comparable average detection performance, as well as low cost per square mile covered. It has the disadvantages of lower detection rates close to shore stations and only periodic vessel refresh.

Satellites carrying AIS units are placed in Low Earth Orbit (LEO) where they travel at about 27,400 km/h at a distance of 650 to 800km above the surface of the earth. A single revolution around the earth takes approximately 90 minutes. As these are LEO satellites, a constellation of satellites is required to provide coverage in a timely method.

Satellite and terrestrial AIS systems provide capabilities offering unique and complementary benefits to national administrations, which mean that both are needed for complete maritime domain awareness. Refer to IALA Recommendation A-124 Appendix 19 (Satellite AIS).

#### ASM and VDE channels

VHF data exchange refers to the exchange of data in a digital manner on specified frequencies within VDES. The ITU identified six duplex channels for VDE-T and two channels for each AIS and ASM use (detailed in Table 2.

The two ASM frequencies were identified specifically to provide increased capability for the transmission of application specific messages. In a terrestrial environment, ASM can be both transmitted and received. ASM can also be received by satellite, similar to the reception of AIS by satellite.

The VDE frequencies were agreed to address the ongoing requirement for digital data exchange as identified in e-navigation. The ability to group frequencies together within VDES will provide for increased bandwidth within the VDE aspect of VDES. The frequencies allocated to VDE can be used individually (as 25 kHz channels) or grouped together to provide 50 kHz or 100 kHz. The increased bandwidth, coupled with revised approaches to access the bandwidth, will support increases in data transfer when compared with existing AIS. Following ITU-WRC 2015, the VDE frequencies were agreed for transmit and receive at the terrestrial level, while work is continuing to enable satellite use of the frequencies to enable a truly global digital data exchange capability.

## Digital VHF, MF and HF

VHF is commonly used worldwide in the maritime industry for general voice communication, transmission/reception of distress and safety information and reception of urgent marine information broadcasts, nominally for ‘line of sight’ distances. VHF has been traditionally based on analogue technologies. Changing user requirements and a demand for more sophisticated services have led to the development of digital mobile radio standards and systems.

Digital VHF should enable full communications – duplex and simplex – with higher data rates and more efficient use of spectrum.

### Digital Selective Calling (DSC) (VHF, MF and HF)

DSC is a tone signalling system, which sends packets of digital data over radio spectrum. The MF/HF DSC distress and safety channels are 2187.5, 4207.5, 6312.0, 8414.5, 12577.0, and 16804.5 (kHz); the VHF DSC distress and safety channel is channel 70.

DSC is similar to the tone dialling on a telephone, but with the ability to include data such as the vessel’s identification number, the purpose of the call, the vessel’s position, and the channel for further voice communications. With DSC there is the ability to call individual vessels directly by use of their MMSIs (similar to a telephone number), or send a signal to vessels in the area – for example when sending a Distress/Urgency call. Table 3 presents the key characteristics of DSC. [[1]](#footnote-1)

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| DSC | 22187.5, 4207.5, 6312.0, 8414.5, 12577.0, and 16804.5 (kHz)  156.525 MHz | VHF – 25 kHz  HF – bandwidth constrained by SSB modulation scheme | VHF – 1,200 bps[[2]](#footnote-2)  HF – 100 bps |

Table 3: DSC characteristics

### Digital VHF, MF and HF Radio (other than DSC)

MF/HF is commonly used worldwide in maritime for general voice communication, transmission/reception of distress and safety information, and reception of urgent marine information broadcasts. Long-range HF communications rely on refraction of signals by the ionosphere. MF can have a range of between 50 - 300 kms, with long-range HF reaching to 4,000 kms. The greater range depends on antenna configuration, power levels and atmospheric conditions.

Other than DSC (previous section refers), MF/HF is based on analogue technologies. Changing user requirements and a demand for more sophisticated services have led to the development of digital mobile radio standards and systems, in the land mobile environment. Digital techniques for HF, including digital voice, have been developed to address the inherent weaknesses of HF such as susceptibility to interference, fading and dropouts due to ionospheric effects and frequent poor voice quality.

Digital HF systems should enable full duplex communications, higher data rates and more efficient use of spectrum.

Table 4 provides the technical characteristics for digital VHF/UHF.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth for a simplex channel | Data Rate |
| Digital VHF/UHF | 156-162 MHz/450-470 MHz | 25 kHz/6.25 kHz | 9.6-19.2 kbps/4.8 kbps |

Table 4: Digital VHF/UHF system characteristics

## Wi-Fi

The Wi-Fi communication system is one that runs across local networks, and is defined by the Institute of Electrical and Electronic Engineers (IEEE)[[3]](#footnote-3). Wi-Fi networks consist of routers and adapters which translate a wired ethernet connection into a local wireless network for devices to connect. Wi-Fi can provide internet access to users. Wi-Fi hot spots may be set up in public places, such as ports, airports and restaurants to enable users to access the internet whilst on the move. Wi-Fi networks may be set up on board a vessel to enable data transfer within the ship, but access to internet is reliant on access through a service provider. Table 5 presents the key characteristics of Wi-Fi.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| Wi-Fi 802.11ai | 2.4 and 5 GHz | 40 MHz | Up to 1.3 Gbps |

Table 5: Wi-Fi system characteristics

The IEEE 802.11ai standard is a recent standard introduced which is solely based on the 5 GHz band and is able to theoretically transfer data at rates up to 1.3 Gbps. The higher frequency 5 MHz channels have a lower range than the lower frequency 2.4 MHz channels, however 2.4 MHz is a very congested band and may experience interference.

## 4G and 5G networks

4G is the 4th generation of mobile telecommunications, succeeding the 3rd generation system, 3G. 4G is defined as a set of standards to provide a given level service for a communication system. Within these standards, various technologies are built, which can then be identified as 4G, if they met the required standards.

Two systems that are considered to meet this standard are WiMax and LTE. WiMax was initially invested in heavily, with the technology offering high speed internet connection within a large coverage areas. However, the uptake of WiMax has been limited and some providers are decommissioning networks. In contrast, LTE (long term evolution) is widely used, with the more recent development, LTE-Advanced (LTE-A) regarded as a fully compliant 4G network.

4G is defined by the set of IEEE standards and LTE-A is a technology that complies with these standards. The LTE-A network uses Orthogonal Frequency-Division Multiplexing (OFDM), by encoding data on multiple frequencies. Table 6 presents the key characteristics of LTE-A.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| 4G – LTE Advanced | 700 MHz, 1.7 to 2.1 GHz and 2.5 to 2.7 GHz | 20 MHz | 600 Mbps (download) |

Table 6: 4G –LTE Advanced system characteristics

5G is a development from the 4G network and is advertised to be delivered from 2020. This latest development includes faster mobile data rates. The updated standards that will define the 5G network are still under consideration, but network trials have been successfully implemented. In bench trials speeds with a peak bitrate of 1 Tbps have been achieved. It is anticipated that realistic rates for 5G will achieve 1.2 Gbps. In addition, it is envisoned that 5G will have a satellite component.

5G developments will ensure a much faster connection than 4G. Not only will the data rate be increased, but the capacity is also intended to increase allowing for more users to access the higher speeds simultaneously. Table 7 provides the technical characteristics for 5G.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| 5G | SHF – above 6 GHz | Greater than 4G | 1.2 Gbps (download) |

Table 7: 5G system characteristics

## Satellite communication systems and services

There is a wide range of satellite services that are currently provided, with plans for new services to be introduced in the near future. Satellite in itself is not a communications technology; rather the satellite carries a payload for communications and uses spectrum that is allocated by altitude. Satellite services are provided from geostationary (GEO) satellites, medium earth orbit (MEO) and low earth orbiting (LEO) satellites.

GEO satellites operate at an altitude of about 36,000 km in orbit over the Equator (0 degrees latitude), at various longitudes. These satellites have an orbital period equal to the rotation of the Earth and appear stationary above a fixed point on the Earth’s Equator. They provide continuous coverage for the majority of the earth’s surface, but do not provide coverage in the polar-regions (e.g. at latitudes typically greater than 70°).

MEO satellites operate at altitudes between 2,000 - 35,786 km. The most common MEO orbits are at just over 20,000 km with an orbital period of 12 hours. These satellites are commonly used for navigation services. MEO have recently been introduced into the Cospas/Sarsat system to support search and rescue (MEOSAR).

LEO satellites operate at altitudes between 80 - 2,000 km. The majority of LEO satellites make a complete revolution of the Earth in approximately 90 minutes. For persistent coverage of any one area of the Earth, there is a need to have a grouping of multiple satellites, known as a ‘constellation’. The footprint of a LEO satellite would be in the realm of 3,281 km or 1,770 nautical miles. These satellites use different orbiting planes and can provide full global coverage, but coverage is reliant on the orbit of the satellite and no one spot on the Earth’s surface can be served continuously by a single satellite.

Inmarsat is an example of a GEO satellite constellation. Inmarsat was originally established on the initiative of the International Maritime Organization (IMO) to operate a satellite communications network for the maritime community, including public safety services. Current data services include support for GMDSS, high data rate internet broadband/data streaming, low data rate, low latency, high availability data reporting, short burst data and store and forward capabilities.

Galileo is an example of an MEO constellation. There are 18 satellites available within the Galileo satellite service. The complete constellation will comprise of 30 satellites, 6 of which are spares.

Iridium is an example of a LEO satellite constellation. Iridium uses a constellation of over 60 cross-linked LEO satellites to provide high-quality voice and data connections, including coverage over polar regions with the use of polar orbiting satellites.

Some sample GEO and LEO satellite options are presented. As satellite technology is developing rapidly, this is not an exhaustive representation but provides a general overview of the existing, and expected, capabilities to address maritime requirements.

### Geostationary satellites (GEO)

Noting that the satellite itself is the means to deploy a specific payload for communications, there are a number of existing or developing technologies that can be deployed on GEO satellites.

#### Inmarsat C

Inmarsat C is a store and forward satellite service used to transmit data from shore-ship, ship-ship and ship-shore. It provides global coverage (excluding the polar regions) and is designed to send low data packages such as position reports, meteorological reports and navigational warnings. The benefits of this technology include the restriction to maritime services, reducing the load on the system.

Inmarsat C is used for low data transmissions. The data rate provided by the Inmarsat C service is 600 bps and works in the L band.

Table 8 provides the technical characteristics for Inmarsat C.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| Inmarsat C | 1626.5-1645.5 MHz (transmit)  1530.0- 1545.0 MHz (receive) | 15-20 MHz | 600 bps |

Table 8: Inmarsat C technical characteristics

Inmarsat Global Express (GX) is the latest satellite service offering from Inmarsat providing higher bandwidth than the existing Inmarsat SwiftBroadband and FleetBroadband services. As a global service, it provides broadband access to vessels outside the reach of normal terrestrial broadband, such as 4G and 5G. With the Ku band becoming increasingly saturated, the Inmarsat GX system has migrated the broadband services to the Ka band. Although the Ka band is more susceptible to rain attenuation, it provides the capacity that is required for delivering a high bandwidth internet connection. The service uses a number of spot beams, giving a high data rate to a wider area, with further steerable beams also available to provide additional capacity where it’s needed. However, this service is not reserved solely for maritime meaning there is a higher risk of system overload.

The Inmarsat GX system functions in the SHF-EHF frequency bands (26.5 - 40 GHz) and provides higher bandwidth for internet connection. The service is expected to facilitate a data rate of 50 Mbps.

Table 9 provides the technical characteristics of Inmarsat GX.

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| Inmarsat GX | 26.5-40 GHz | 64 MHz per spot beam  200 MHz for high capacity overlay | 50 Mbps |

Table 9: Inmarsat Global Express system characteristics

### Low Earth Orbiting satellites (LEO)

Noting that the satellite itself is the means to deploy a specific payload for communications, there are a number of existing or developing technologies that can be deployed on LEO satellites.

#### Iridium

Iridium has been effectively providing satellite communication services since 2001. While the initial service was seen as effective for rescue services and missions to remote areas of the globe, the demand for services has led to the development of Iridium Next. The revised basic functions include additional bandwidth, end-to-end IP technology and the incorporation of earth imaging and other secondary payloads.

The Iridium satellite system uses L band transponders to communicate with users, using frequencies in the band 1616 - 1626.5 MHz. It provides up to 134 kbps bidirectional (OpenPort broadband service).

Table 10 provides the technical characteristics of Iridium (Pilot).

|  |  |  |  |
| --- | --- | --- | --- |
| System | Frequency | Bandwidth | Data Rate |
| Iridium (Pilot) | Ground users - 1616 – 1626.5 MHz (L-band)  Terrestrial gateway 29.1 – 29.3 GHz | 31.5 kHz | Up to 134 kbps |

Table 10: Iridium (Pilot) system characteristics

The differences in the technologies are not only related to area of coverage and data rate, but also to the transmission process - for example, some are addressed (point to point only), while others can be addressed, broadcast to a group of ships or broadcast to a geographic area.

## Overview of Digital Communications Systems

Table 11 provides a summary matrix outlining the communication technologies.

| Communication Technology | Data rate | Infrastructure | Coverage | Transmission | Maritime / public |
| --- | --- | --- | --- | --- | --- |
| NAVDAT | 12-18 kbps | Based on NAVTEX | 250/300NM | Broadcast | Maritime |
| VDES VDE | 307 kbps | VHF Data link, RR Appendix 18 channels | Line of sight, approx 15NM-65NM  Satellite component provides further coverage | Addressed / broadcast | Maritime |
| VDES ASM | 19.2 kbps | VHF Data link, RR Appendix 18 channels | Line of sight, approx 15NM-65NM | Addressed / broadcast | Maritime |
| Wi-Fi (IEEE 802.11ac) | 1,300 kbps | Routers/Access points | 50m | Addressed | Public |
| Digital VHF | 9.6-19.2 kbps | Base station/mobile radios | Line of sight, approx 15NM-65NM | Addressed | Maritime |
| Digital HF | 19.2 kbps | Base station/mobile radios | Global | Addressed | Maritime |
| 4G (including LTE) | 600 Mbps | 4G Base stations | 5-30km (3-6 NM) | Addressed | Public |
| 5G | 1,200 Mbps | 5G base stations | 5-30km (3-6 NM) | Addressed | Public |
| GEO Satellite |  |  |  |  |  |
| Inmarsat C | 600 bps | Satellite service | Global, spot beams | Addressed / broadcast | Maritime |
| Inmarsat GX | 50 Mbps | Satellite functioning on Ka band | Global, spot beams | Addressed / broadcast | Cross Industry |
| LEO Satellite |  |  |  |  |  |
| Iridium | Up to 134 kbps | Satellite functioning on L band | Global, dependent on constellation size | Addressed / broadcast | Cross Industry (Iridium Pilot Maritime) |

Table 11: Summary of communication technologies

# Positioning, Navigation and Timing

## Introduction

Positioning, Navigation and Timing (PNT) information is used widely in the maritime sector, both to navigate ships and in Aids to Navigation (timing and positioning). There are a number of systems available that deliver PNT.

More details of these systems can be found in the IALA World Wide Radio Navigation Plan (WWRNP).

## Electronic Position Fixing Systems

### Global Navigation Satellite Systems

Global Navigation Satellite System (GNSS) is the generic term for a satellite system that provides a world-wide position determination, with time and velocity capability, for multi-modal use.

GNSS is based on a constellation of active satellites which continuously transmit coded signals in one or more frequency bands. These signals can be received by users anywhere on the earth’s surface to determine the user’s position and velocity in real time, based on ranging measurements.

If a GNSS is recognised by the IMO as a component of the World Wide Radio Navigation System (WWRNS), as set out in IMO Resolution A.1046 (27), the receivers of that GNSS will satisfy the IMO carriage requirements for position fixing equipment referred to in Chapter V of the SOLAS Convention.

GNSS receivers in combination with other equipment are able to provide PNT information such as:

* absolute positioning;
* relative positioning (this can be further processed to derive speed over ground (SOG), course over ground (COG), etc.); and
* timing

This information may refer to a stationary observer (static positioning) or to a moving observer (kinematic positioning).

Several Global Navigation Satellite Systems (GNSS) have been deployed, fully or partially, or are under development. GPS, GLONASS, BeiDou and Galileo have been recognised as components of the WWRNS. It is planned that regional GNSS components like QZSS and NAVIC will become operational in the next few years and may be submitted for recognition in WWRNS in due course. GPS, Galileo, BeiDou, QZSS and NAVIC operate interoperable services under the framework of the International Telecommunication Union (ITU).

#### Global Positioning System

The Global Positioning System (GPS) is a three-dimensional positioning, velocity and time system that became fully operational in 1995. The system is operated by the United States Air Force on behalf of the United States Government.

The U.S. Government provides two levels of GPS service. The Precise Positioning Service (PPS) provides full system accuracy to designated users. The Standard Positioning Service (SPS) provides accurate positioning to all users.

GPS has three major segments: space, control and user. The GPS Space Segment consists of a nominal constellation of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) high orbits at an inclination angle of 55 degrees and with a 12-hour period.

The GPS SPS is available on a non-discriminatory basis, free of direct user fees, to all users with an appropriate receiver. The service satisfies the requirements for general navigation and harbour approach with a horizontal position accuracy of 9 metres (95% probability) [[note: 3]](http://www.iala-aism.org/wiki/ialawiki/index.php/Navguide:_Chapter_4_-_e-Navigation#cite_note-3).

A modernisation 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 termed M-Code.

Further information on GPS can be found at the USCG NAVCEN website ([www.navcen.uscg.gov](http://www.navcen.uscg.gov)). The website also has a link to the latest United States Federal Radionavigation Plan that provides a comprehensive account of current and future developments for GPS.

#### Global Orbiting Navigation Satellite System

The Global Orbiting Navigation Satellite System (GLONASS) is a three-dimensional positioning, velocity and time system managed by the Russian Space Agency for the Russian Federation.

It is available on a non-discriminatory basis and free of direct user fees to all users with an appropriate receiver. With a full complement of 24 satellites, the service satisfies the requirements for general navigation and gives a horizontal position accuracy in the region of 12.4m (95%) over any 24-hour interval, given a position dilution of precision (PDOP) of 2. [[note: 4]](http://www.iala-aism.org/wiki/ialawiki/index.php/Navguide:_Chapter_4_-_e-Navigation#cite_note-4)

Recent launches have included the improved GLONASS M satellites with a second civil signal. Since 2011, the constellation is being replenished with GLONASS-K satellites that provide a third civil signal on L3.

GLONASS satellites use Frequency Division Multiple Access (FDMA). However new satellites will provide additional signals using code division multiple access (CDMA), to become interoperable with other GNSS.

Further information on GLONASS and future developments can be found on the Russian Space Agency, Information Analytical Centre website ([www.glonass-ianc.rsa.ru](http://www.glonass-ianc.rsa.ru)).

#### Galileo

Galileo is the European GNSS designed to be interoperable with other GNSS, managed and operated under civil control. The Galileo programme is currently in its deployment phase and is due for completion in 2020. Initial services were declared in 2016.

Galileo will offer the following services:

1. An Open Service (OS): With positioning accurate to around 1 metre using up to three different frequencies (E5a, E5b and L1), free of user charges and providing positioning and synchronisation information intended mainly for high-volume satellite navigation applications.
2. A Public Regulated Service (PRS): Restricted to European government-authorised users, for sensitive applications which require a high level of service continuity. It will use strong, encrypted signals. It may be accessed by non-EU states and international organisations subject to bilateral agreements.
3. A contribution to the Search and Rescue Service (SAR) of the COSPAS-SARSAT system: Galileo’s worldwide search-and-rescue service will forward distress signals to a rescue coordination centre by detecting emergency signals from beacons and relaying messages to them in near real time.
4. A Commercial Service (CS): Encrypted for authentication purposes and offering very high accuracy to the sub-decimetre level, it will target applications for professional or commercial use. It will offer improved performance and data with greater added value than that obtained through the open service.

Galileo will use a constellation of 24 satellites to achieve its positioning performance targets but aims to have a constellation of 30 satellites when fully operational (including in-orbit spares). Further information on Galileo can be found at the following website: <http://ec.europa.eu/growth/sectors/space/galileo/>

#### BeiDou

BeiDou Navigation Satellite System (BDS) is China’s independently constructed and operated GNSS system. It can be compatible with other GNSS in the world. BeiDou can provide all-time, all-weather PNT services with high accuracy and high reliability for all kinds of users. A joint office established by related governmental departments, China Satellite Navigation Office (CSNO) is in charge of management on the construction, application promotion and industrialisation of BDS.

BDS consists of three major components: the space constellation, the ground control segment and the user segment. The space constellation consists of 5 GEO satellites and 30 non-GEO satellites. Upon completion of the full system, BDS will provide positioning, velocity measurement and timing services to users worldwide. It can also provide wide area differential services with the accuracy of better than 1m.

It is expected that when fully operational, the BeiDou constellation will consist of approximately 40 satellites and be capable of providing global coverage. For further details on BDS, including the number of satellites currently in orbit, please refer to the CSNO website [note: 6].

Further information on BDS can be found on the CSNO website (<http://en.beidou.gov.cn/index.html>)

### Regional systems

#### Quasi-Zenith Satellite System

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on three satellites in highly elliptical, inclined orbits and one geo-stationary satellite. The final constellation is expected to consist of 7 satellites, with each transmitting 6 signals in the L-band: 3 in L1, 1 in E6, 1 in L2 and 1 in L5. The signal in E6 (L6) aims to support a commercial service with high data rate (2 kbps). Full implementation will also provide augmentation services to GPS and QZSS.

Further information is available at <http://QZSS.go.jps/>.

#### Indian Regional Navigational Satellite System

The Indian Regional Navigational Satellite System (IRNSS) with an operational name of NAVIC (Navigation with Indian Constellation) will be an independent navigation system covering the Indian region through a space segment of 3 GEO satellites and 4 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 NAVIC services are anticipated:

* Open Service using signals in the L5 and S bands;
* Precise Positioning Service using signals in the L5 and S bands; and
* 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. Owing to the limited coverage of the NAVIC 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.

### Differential Global Navigational Satellite System

The aim of GNSS augmentation services such as Differential Global Navigational Satellite System (DGNSS) is the improvement of GNSS-based positioning in a given area. In this context, various methods can be applied to increase the accuracy of GNSS-based positioning, and to verify the integrity of applied components (systems, services) and provided data. An essential basis for the provision of DGNSS service is own GNSS measurements gathered in real time at single reference stations or a network of stations.

DGNSS service provides correction in terms of ranging errors per satellite in view. This principle is applied by IALA Beacon DGNSS providing range and range rate corrections, derived at a reference station site from differences between surveyed and known distances to satellites in view. Satellite Based Augmentation Systems (SBAS) provide an area correction parameter, whose application enables the determination of range and range correction for users in large-scale regions such as continental Europe. In this case, a network of ranging and integrity monitoring stations (RIMS) is used to measure and model the spatial varying error behaviour.

Centimetre-level accuracies can be achieved by DGNSS services employing the application of real time kinematic techniques (RTK) for positioning. The gain of accuracy is achieved by the common processing of range and phase measurements collected at reference station and user site, to apply single and double difference methods during position determination.

In safety-critical applications, DGNSS services should be enriched with integrity functions, realising the monitoring of data and system integrity in real time. The monitoring can be realised by plausibility and consistency tests as well as methods estimating error behaviour and budgets. Results of the integrity monitoring informs the user about the current usability of applied components and provided output data.

The DGNSS service provision is realised by radio signals carrying augmentation, correction and integrity data. Users operating in service areas and equipped with appropriate receivers can use this augmentation data to:

* enhance accuracy of GNSS based positioning;
* notify of faulty satellites or GNSS failure;
* detect satellite signals with increased propagation errors;
* exclude disturbed signals from positioning; and
* be informed about the usability of services or other information.

Currently, DGNSS services are provided for operational satellite navigation systems such as GPS and GLONASS. In principle, similar DGNSS services can be provided for developing GNSS such as GALILEO, BeiDou and QZSS.

Each DGNSS service can be separated into two parts - generating and distributing the augmentation data. The generation of DGNSS augmentation data requires own GNSS measurements gathered at a single reference station or a network of stations. Different DGNSS messages and services may use different generation methods and means of dissemination. At present, certain communication channels used for the provision of DGNSS augmentation data are assigned to specific DGNSS services. For example, the provision of DGNSS augmentation data is realised by terrestrial radio transmitters (i.e. IALA beacon transmissions or AIS) or via satellite transponders (SBAS).

#### Terrestrial augmentation systems

The following sections consider the different correction methods which used ground-based infrastructure.

##### IALA Beacon DGNSS

The aim of IALA beacon DGNSS is the provision of non-encrypted differential corrections, as well as integrity information, to maritime users to improve accuracy and integrity of GNSS based determination of position, velocity and time data (PVT). The method of differential positioning was developed in the 1990s, is internationally accepted and supported in most coastal waters, especially in areas of high traffic density. The differential corrections are determined at known positions of reference stations or a network of stations. For this purpose, the difference between expected and measured ranges is used to derive actual range and range rate corrections.

Additionally, integrity monitoring functionalities are implemented to assess the usability of GNSS signals and provided DGNSS service.

The radio link used for the provision of DGNSS correction and integrity data is internationally defined at ITU (Recommendation ITU-R M.823-3). At present, the DGNSS signal transmission is realized in the maritime radionavigational band (283.5 to 325 kHz) [note: 7]. At user sites, type-approved DGNSS radio beacon receivers (meeting IEC 61108-4 test and performance standards) are necessary to enable the ship-side use of DGNSS services for an improved PVT data determination.

The recapitalisation of DGNSS infrastructure is an ongoing process. Of the options available, some service providers have opted to replace existing hardware with similar dedicated Reference Stations and Integrity Monitors (RSIM); some have invested in software RSIM; while others have adopted a network of reference stations to create virtual RSIMs. Other solutions, such as integration with SBAS may evolve within the enhancement of the maritime PNT system.

The full list of about 400 maritime radiobeacon based DGNSS stations (as notified to IALA by aids to navigation authorities) is at the IALA website ([www.iala-aism.org](http://www.iala-aism.org)).

Refer to IALA publications:

* Recommendation R-1115 (Provision of maritime radionavigation services in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Region 2 and 3);
* Recommendation R-121 (Performance And Monitoring of DGNSS Services In The Frequency Band 283.5-325khz); and
* Guideline 1112: (Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz).

##### AIS for DGNSS Transmissions

Automatic Identification System (AIS) is a ship to ship and ship to shore data exchange and broadcast system, operating in the VHF maritime band. It is described in more detail in Section 7.

AIS has the capability of providing DGNSS corrections to onboard equipment using standardised transmissions (Message No 17) as described in IALA Recommendation A-124.

##### Maritime Phase-Based GBAS (MGBAS)

In the past few decades, the development of phase-based measurement techniques was driven by surveying needs, to achieve position accuracies with GNSS in the centimetre level. In IALA Recommendation on the Future of DGNSS (R-135), the RTK technique is mentioned as an approach to meet maritime requirements on high-precision positioning in port areas and for docking. Several manufacturers of maritime GNSS/DGNSS equipment provide solutions supporting RTK-based positioning.

It is noted that RTK is a short-range system, and that there is a need to introduce monitoring and assessment of the integrity of RTK services and RTK based positioning in the context of safety-critical applications.

##### RTK over AIS

In survey applications, the RTK correction information is usually distributed to users via VHF/UHF radio modems or via commercial broadband internet. However, when used in hydrographic measurements further away from the shoreline, these communication options might not be always available. The communication options in these areas would then be via satellite or via AIS (the latter is also available only within coastal VHF coverage, usually up to 50 - 70 kms from the coast line).

RTK over AIS is in operational use for selected user groups in some countries and it has been reported to function without major problems and deliver the required positioning accuracy.

When using RTK over AIS, it should be noted that it puts a high demand on the VHF Data Link. Other limitations of this technique are that only one mobile user can be served by one AIS base station at a time, there is reduced understanding of accuracy due to rapid atmospheric fluctuations and that it may not be applicable in areas of high channel loading. The channel loading problem may be addressed in the future by using the additional channels allocated for VDES.

#### Satellite Based Augmentation Systems

Satellite Based Augmentation Systems (SBAS) support wide-area or regional augmentation through the use of additional satellite-broadcast messages. The basic arrangement is to use a set of monitoring stations (at precisely known positions) to receive GNSS signals. These will be processed in order to obtain estimations of these errors that are also applicable to the users (i.e. ionospheric errors, satellite position/clock errors, etc.). Once these estimations have been computed, they are transmitted to the users by means of a GEO satellite.

##### Wide Area Augmentation System

The Wide Area Augmentation System (WAAS) has been implemented by the US Federal Aviation Authority (FAA) to support the use of GPS for general and commercial aviation over 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. Further information on WAAS can be found on the USCG Navigation Centre website ([www.navcen.uscg.gov](http://www.navcen.uscg.gov)).

##### European Geo-stationary Navigation Overlay Service

The European Geostationary Navigation Overlay Service (EGNOS) is the European satellite-based augmentation system that provides safety critical navigation services to aviation, maritime and land-based users over most of Europe. EGNOS augments the GPS L1 Coarse/Acquisition (C/A) civilian signal by providing corrections and integrity information.

EGNOS provides three services:

* + - * Open Service (OS), freely available to any user. The main objective of the EGNOS OS is achievable positioning accuracy by correcting several error sources affecting GPS signals. (https://egnos-user-support.essp-[as.eu/new\_egnos\_ops/sites/default/files/library/official\_docs/egnos\_os\_sdd\_v2\_2.pdf](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_os_sdd_v2_2.pdf));
      * Safety of Life (SoL) Service, provides the most stringent level of signal-in-space performance developed primarily to support aviation. Its use in the maritime sector is being explored with a view to supporting maritime SoL users in the future.

([https://egnos-user-support.essp-](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf)  [sas.eu/new\_egnos\_ops/sites/default/files/library/official\_docs/egnos\_sol\_sd](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf) [d\_in\_force.pdf](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf));

* + - * EGNOS Data Access Service (EDAS) is the EGNOS terrestrial data service which offers ground-based access to EGNOS data in real time and also in a historical FTP archive to authorised users (e.g. added-value application providers) ([https://egnos-user-support.essp-](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_edas_sdd_v2_1.pdf)  [sas.eu/new\_egnos\_ops/sites/default/files/library/official\_docs/egnos\_edas\_sdd\_v2\_1.pdf](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_edas_sdd_v2_1.pdf)).

The EGNOS Space Segment comprises 3 geostationary (GEO) satellites. The EGNOS Ground Segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), two Mission Control Centres (MCC), six Navigation Land Earth Stations (NLES), and the EGNOS Wide Area Network (EWAN) which provides the communication network for all the components of the ground segment.

Further information on EGNOS can be found via website <http://www.egnos-portal.eu/>and <https://egnos-user-support.essp-sas.eu/>).

##### Multi-Satellite Augmentation System

In Japan, the Multi-Satellite Augmentation System (MSAS) is a SBAS similar to EGNOS and WAAS. MSAS has been commissioned for aviation use, with two GEO-links using the L1 band via dedicated satellites, shared with communications and meteorological missions. The system has been operational since 2007 and there are plans to add additional services on L5 in the future [note: 8]. Further information on MSAS can be found via the website: ([www.kasc.go.jp/\_english/msas\_01.htm](http://www.kasc.go.jp/_english/msas_01.htm)).

##### GPS-Aided Geo Augmented Navigation System

India is developing a GPS-Aided Geo Augmented Navigation system (GAGAN), which is a SBAS similar to WAAS and EGNOS. GAGAN includes 8 reference stations, 1 mission control centre, 1 up-link station and 1 GEO-link through the L1/L5 transponder on the INMARSAT 4-F1 satellite. At the time of writing, further information on GAGAN may be found at [www.isro.org](http://www.isro.org).

##### System for Differential Corrections and Monitoring

Russia is developing an augmentation to provide corrections for GLONASS and GPS called the System for Differential Corrections and Monitoring (SDCM). This system will consist of 3 geostationary satellites, assigned PRN codes 125,140 and 141. Two satellites have been launched and are in operation.

##### Korea Augmentation Satellite System

Republic of Korea is developing a Korea Augmentation Satellite System (KASS), which is an SBAS similar to WAAS and EGNOS. KASS includes 7 reference stations, 2 master stations, 2 up-link stations, and 2 operational control centres. Upon completion of system development and establishment, scheduled in 2019, KASS will begin to provide its open service in 2020. It will then undergo a series of system certification processes in the next several years before its provision of safety of life (SoL) service in the aviation sector in October 2022. Further information on KASS can be found via website (www.kass-eng.re.kr).

### Terrestrial systems

#### Loran-C

Loran–C is a hyperbolic radionavigation system that was developed during the 1960’s to meet U.S. Department of Defense requirements. The Russian Federation operates a similar radionavigation system called CHAYKA. There are currently about 19 Loran - C and CHAYKA chains operating around the world. The principal coverage areas include Saudi Arabia, China Sea, Korea, North West Pacific, Russian Federation and North West Europe.

Loran - C chains comprise between three to five stations that have a spacing of 600 to 1000 nautical miles. The signal format is a structured sequence of specially designed radio pulses on a carrier wave frequency centred on 100 kHz. One of the stations is designated as the ‘master’ and transmits groups of 9 pulses. The other stations are called ‘secondaries’ and these transmit groups of 8 pulses.

The spacing between groups of ‘master’ pulses from a single chain is a characteristic unique to that chain and is referred to as the Group Repetition Interval (GRI).

The 100 kHz carrier wave frequency favours the propagation of a stable ground wave over long distances. Careful signal design allows Loran receivers to determine positions using the ground wave and reject the delayed sky wave that would potentially distort the received signal.

The transmissions from each chain are monitored and controlled continuously. System abnormality indicators are built into the signal format and can be identified by the receiver providing inherent integrity warnings.

#### eLoran

Enhanced Loran (eLoran) is a terrestrial navigation system developed from Loran-C. It is a Positioning, Velocity, and Timing (PVT) service for use by land, sea and air navigation, as well as other applications reliant on timing data.

eLoran is independent of and has dissimilar failure modes to GNSS, and therefore complements GNSS. Although offering reduced accuracy, it will allow GNSS users to retain the safety, security and economic benefits of GNSS, even when their satellite services are disrupted. eLoran provides positional accuracy in the region of 8 - 20 metres and time and frequency performance (to stratum-1 level) similar to current GNSS.

eLoran differs from Loran-C as it uses an all-in-view method of operation, calculating the distance to all eLoran stations in view. eLoran stations are also synchronised with, but independently of, GNSS time. Synchronising to a common time source allows receivers to employ a mixture of eLoran and GNSS signals. eLoran receivers calculate the distance from each station by firstly assuming that the entire earth’s surface is covered in sea-water. By knowing the speed of the signal over sea-water, along with the times of transmission and reception, a pseudorange can be calculated. This pseudorange is then adjusted to take into account the propagation delays due to the signal passing over land. These delays are called Additional Secondary Factor delays (ASFs). ASFs are measured by the service provider and are supplied to users as a database built into their receivers. ASFs may change slightly due to weather or seasonal effects, reducing the efficiency of the correction and affecting accuracy. However, this is resolved by installing a differential Loran reference station nearby, which is able to measure the difference and calculate a correction. The correction information is then passed back to the eLoran station for dissemination to the user over the eLoran data channel.

The inclusion of a data channel as part of the main transmission is one of the inherent features of eLoran. It can be used to provide other data services in addition to differential corrections.

For more information, the reader is encouraged to seek advice from the Radio Technical Commission for Maritime Services Special Committee 127 (SC-127) on eLoran Systems.

#### Compatibility Between eLoran and Loran-C

Legacy receivers are able to use both eLoran and Loran-C signals as eLoran stations form part of the presently organised chains. However, legacy Loran-C receivers will likely not provide the user with the best accuracy performance.

Users should ensure their receivers are able to decode the Loran Data Channel to receive integrity alerts, UTC time and differential-Loran correction data. They should also ensure their receiver is capable of storing and applying up-to-date ASF data.

#### Receiver Autonomous Integrity Monitoring

Receiver Autonomous Integrity Monitoring (RAIM) is a technology developed to assess the integrity of GNSS signals, and therefore the integrity of GNSS-based positioning. This kind of integrity monitoring is autonomously realized within the user’s receiver with special importance for safety critical applications, such as aviation and maritime.

Range measurements are required from at least four GNSS satellites to enable the determination of position, velocity and time data. However, the application of RAIM in a navigation receiver requires redundancy in the range measurements.

Safety-critical RAIM algorithms might use only “Fault Detection” (FD) or “Fault Detection and Exclusion” (FDE), which enables the continuation of operation in the presence of a single GNSS satellite and signal failures. To detect a faulty satellite, at least five range measurements are required, whereas to isolate and exclude a faulty satellite, at least six range measurements are required. While RAIM can detect many failure modes, it cannot detect some failures affecting multiple satellites.

The upcoming availability of various GNSS will increase the usable number of navigation signals for RAIM-based positioning. New and modernized GNSS supports the provision of GNSS signals in two or more frequency bands and therefore improves the capability of GNSS based ranging.

Future advancement in RAIM algorithms should improve the availability and continuity of RAIM based positioning. Such enhanced RAIM techniques - called Advanced RAIM (ARAIM) - may become available to maritime users ([www.navipediA.net/index.php/araim](http://www.navipediA.net/index.php/araim)).

#### Ranging mode

Studies are being conducted on the benefit of expanding the functionality of existing systems by providing a timing signal from which the user may then calculate their position independently from GNSS. This is known as Ranging Mode (R-mode).

At present, the IALA MF beacon system and AIS services are being considered as candidates for modification to add R-mode functionality. By providing timing information over their normal MF or VHF transmissions, a shipboard receiver may then calculate a distance (range) to the transmitter. By calculating the range to several stations, the user is able to calculate the ship’s position. Coverage, geometry and interference issues would need to be investigated.

The provision of R-Mode services would require the availability of an accurate non-GNSS timing source at the transmitter. High stability clocks could be an expensive option and it is more likely that time would be sourced from a low frequency radio time clock or eLoran.

## Radar Aids to Navigation

Radar aids to navigation are devices that provide returns to a ship’s radar that help to locate and/or identify a navigation mark. The IMO carriage requirements contained in Chapter V, Regulation 19 of the SOLAS Convention 1974 (as amended), states all ships of:

* 300 gross tonnage and upwards are to carry a 9 GHz radar;
* 3,000 gross tonnage and upwards are to be fitted with a 3 GHz radar or, where considered appropriate by the Administration, a second 9 GHz radar.

Some administrations may impose other carriage requirements.

IMO Resolution MSC.192 (79) Adoption of the Revised Performance Standards for Radar Equipment (December 2004) states that 9 GHz radars should be capable of detecting radar beacons, SARTs and radar target enhancers. By omission, 3GHz radars are not required to detect radar beacons and SARTS. With the removal of the 3GHz radar racon detection requirement, ship-owners are free to use higher performing radars, often referred to as New Technology (NT) radars, discussed below.

9 GHz radars are also extensively carried by vessels not covered by SOLAS or local regulation. Due to this high rate of carriage, radar aids to navigation in the 9 GHz band are especially useful.

### Radar Reflectors

A radar reflector is a passive device designed to return the incident radar pulses of electromagnetic energy back towards the source and thereby enhance the response on the radar display. By design, a radar reflector attempts to minimise absorption and random scattering effects.

A radar reflector is generally installed as a supplementary device at sites that would also be marked with a light. The main objectives are to enhance:

* target detection at long ranges (for example, for landfall navigation);
* target detection in areas of sea or rain clutter; and
* radar conspicuity of aids to navigation to reduce the risk of collision damage.

The performance of a radar reflector can be defined in terms of its effective radar cross section (RCS). This is a value determined by comparing the strength of radar signals returned by the radar reflector with the equivalent return from a radar reflective sphere of 1m2 reflecting area.

The range at which a radar reflector target can be detected is dependent on the heights of the radar antenna, the reflector and the output power of the radar. There are analogies to the geographical range of visual marks. The radar performance of corner cluster reflectors may vary considerably from one make to another.

Use of small radar reflectors can also be subject to multipath fading effects. Please see IALA Guideline No.1010 on Racon Range Performance for a discussion on multipath fading.

Most radar reflectors are designed for use by 9 GHz radars. The reflectors can also be used with 3 GHz radars; however, the effective radar cross section is about an order of magnitude less.

### Radar Target Enhancers

A Radar Target Enhancer (RTE) is a device that amplifies and returns the pulse from a ship’s radar to give an enhanced image on the radar screen. The returned signal from an RTE is not coded. The RTE was designed primarily for buoys and small vessels that might normally carry a passive radar reflector. RTE testing has shown RTEs to have provided an effective radar cross section (RCS) of about 100 m2, compared with an RCS of 20 to 30 m2 for passive radar reflectors typically fitted to buoys.

To date, commercially available RTEs only operate in the 9 GHz band. RTE use is subject to multipath fading effects.

### Radar Beacons

Radar beacons (racons) are receiver/transmitter devices operating in the maritime radar frequency bands (9 and 3 GHz) that enhance the detection and identification of certain radar targets. Please note that IMO MSC.192 (79) has done away with the requirement for 3GHz radar to detect racons.

A racon responds to the presence of a ship’s radar by sending a characteristic pulse train. The response appears as a coded mark (or “paint”) on the ship’s radar display (refer Figure 12) that highlights the range and bearing of the racon. The display paint can be fixed to a specified length or can be dependent on the radar range setting. It uses a Morse Code letter character for identification.

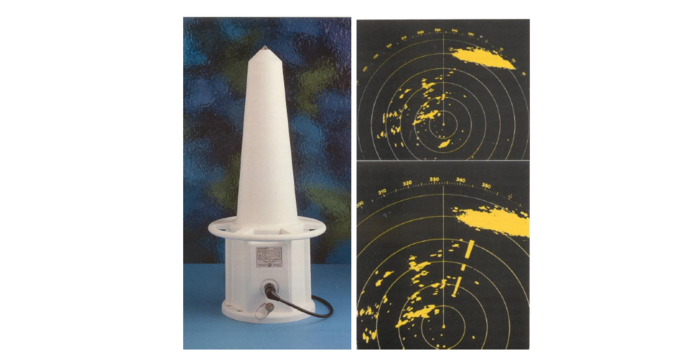
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_4-9-3_Figure24_A_Racon_and_Radar_Display_with_and_without_Racon_Character.png)

Figure 12*: A Racon (left) and a* Radar *Display (right) with and without the Racon character*

#### Applications

A racon is generally considered to be a supplementary aid to navigation installed at sites that would also be marked with a light. The number of vessels capable of making use of a racon is effectively unlimited.

A racon can be used for:

* ranging and identification of positions in ice conditions or on inconspicuous or featureless coastlines;
* identification of aids to navigation, both sea-based and land-based;
* landfall identification;
* indicating centre and turning points in precautionary areas or Traffic Separation Scheme (TSS);
* marking hazards;
* indicating navigable spans under bridges; and
* identifying leading lines.

### Frequency-Agile Racon

A frequency-agile racon responds on the frequency on which it is interrogated and the response can be re-painted on each radar sweep. The purpose of frequency agility is to provide a signal to the radar that is within the receiver bandwidth of the radar.

#### Signal Characteristics

Racons operate in the 9 GHz band with horizontal polarisation, and/or in the 3 GHz band, with horizontal and optional vertical polarisation.

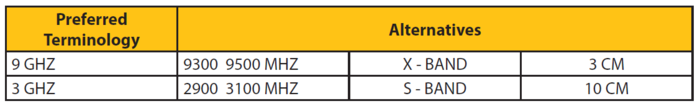
[](http://www.iala-aism.org/wiki/ialawiki/index.php/File:Navguide_2014_table18.PNG)

Table 12: Preferred terminology for the description of Racon Operating Frequencies

### Racon Performance Criteria

The availability of a racon is the principal measure of performance determined by IALA. In the absence of any specific considerations, IALA recommends that the availability of a racon should be at least 99.8%.

For more information on racons, refer to the following IALA publications:

* Guideline 1010 on Racon Range Performance
* Recommendation R-101 on Maritime Radar Beacons (Racons)
* Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability
* Recommendation O-113 for the Marking of Fixed Bridges over Navigable Waters

### Racon Technical Considerations

There are a number of technical considerations in the use of racons to assist with the navigation of a ship:

* To avoid masking other features on the radar display, the racon response is usually switched on and off on a pre-set cycle;
* The angular accuracy of the bearing between the ship and racon depends entirely on the interrogating radar, while the accuracy of the range measurement depends on both the radar and racon;
* When racons are used in leading line applications, an alignment accuracy of about 0.3 degrees can be expected; and
* When a ship is very close to a racon, side-lobes from the radar antenna can trigger the racon. The resulting multiple responses on the radar display may be a distraction and can mask other targets. Side-lobe suppression techniques are standard features of frequency agile racons.

### Use with New Technology Radars

All currently available and installed racons are designed for use with high power pulse radars. In comparison, New Technology (NT) radars use low power transmissions with long pulses. Due to the low received peak signal strength, long pulse at the racon and modulation technique, current racons may not detect NT radars and may not transmit a response usable by NT radars. Studies have shown that pulsed NT radars are able to reliably trigger racons at shorter ranges than would have been achieved with a conventional magnetron pulsed radar. The IMO regulations regarding X band radars and racons remain unchanged and although detection and triggering range might be reduced, it is the responsibility of manufacturers of X band NT radars to retain racon functionality.

Despite changes to the IMO regulations relating to S band racons, existing racons with 3 GHz capability will continue to be useful to 3 GHz pulse radars of both Magnetron and pulsed New Technology variants. Advanced clutter reduction techniques of NT radars do not automatically mean that racons are no longer useable. Some manufacturers are continuing to provide racon compatibility in their NT 3 GHZ radars.

Please refer to Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability for more information on NT radars.

### Radar Referenced Positioning

Algorithms may be developed to allow the radar display to be overlaid upon the electronic chart using detectable recognised navigational features (racons, passive radar beacons or land edge patterns etc.). This technique, although unlikely to challenge the accuracy of a GNSS based position fix, might be adopted as part of a PNT integrity assessment and/or as a back-up in the event of GNSS service or equipment failure or corruption.

## Non-radio Positioning Systems

### Inertial systems

Many studies have been carried out on the integration of GNSS with Inertial Measurement Units (IMU) for marine navigation. There exist various grades of IMU, from the very expensive navigation grade, through to tactical grade and low cost units based on the Micro Electro Mechanics System (MEMS). The IMU grade characterizes the achievable performance of data provision covering velocities and orientations. A small IMU grade is associated with higher drift rates. Depending on the different drift rates, an IMU can provide contingency for various lengths of GNSS outages.

In combination with a GNSS compass, an IMU can provide accurate and stable heading data for longer GNSS outages. None of the currently available inertial systems is capable of maintaining all levels of navigation accuracy during a lengthy outage of GNSS. For ocean areas, both navigation and tactical-grade IMUs will give protection for appreciable outages over 15 minutes and navigation grade IMUs approximately 1 hour. For coastal areas, the required accuracy of 10 meter could be obtained for 3.5 minutes with a navigation-grade IMU and 1.5 minutes with a tactical grade IMU.

### e-Pelorus

An electronic pelorus (ePelorus) is a device for taking bearings of visual marks and converting them to an electronic format for input to an electronic chart system. Such a device would enable the integration of visual AtoN with e-navigation.

The feasibility of constructing a low-cost ePelorus from off-the-shelf components is being investigated to demonstrate its effectiveness as a backup, and to evaluate the potential for integrating visual AtoN with e-navigation.

# Testbeds

The term testbed is used across many disciplines to describe a platform that is used for research, development or testing. Testbeds generally involve rigorous, transparent and replicable testing of scientific theories, innovative solutions, computational tools and new technologies.

IALA Guideline 1107 (on Planning and Reporting Of E-Navigation Testbeds) states that e-navigation testbeds allow for early identification and assessment of new system functionality, operational usability, areas of enhancements, identification of weaknesses and socio-technical impact. Such testbeds should not be limited or restricted by current architecture, data structures or procedures.

Note that not all testbeds may lead to commercial implementation of solutions.

## Testbed information

As e-navigation evolves from concept to operational reality, the importance of testbeds continues to grow.

In order for e-navigation solutions to have global application, IALA facilitates the collation and sharing of the outcomes of testbeds. A list of testbeds that are known to IALA can be found at:

<http://www.iala-aism.org/products-projects/e-navigation/test-bedsprojects/>

Testbed managers are encouraged to share results (including interim and final reports) of testbeds with the maritime community, through IALA. IALA can post testbed findings, including an executive summary and description, as provided by the testbed manager, at the testbeds page of the IALA website. It is then available to everyone involved with e-navigation and testbeds.

It is important that outcomes or lessons learnt from test-bed projects be considered in the context of the main elements of the IMO Strategy Implementation Plan (i.e. user needs, architecture, gap analysis and solutions that are the subject of cost-benefit and risk analyses).

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**Notes**

1. A registry is simply a bookkeeping device where definitions/specifications are kept in organised locations known as registers. the registry eases the tasks of development of new things, by providing a centralised source for finding definitions/ specifications
2. Refer to in particular MSC85/26, Annex 20, paragraphs 9.9.1., 9.1.5, and 9.9.3.
3. GPS Performance Standards, 2008.
4. United Nations Office for Outer Space Affairs, “Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems”, 2011
5. At the time of writing, further information on Galileo may be found on the internet <http://ec.europA.eu/enterprise/policies/satnav/>galileo/index\_en.htm
6. At the time of writing, further information on BeiDou may be found on the internet hhttp://www.en.beidou.gov.cn/csnclist.html
7. A 1kW transmitter will generally allow position fixing to better than 10 metres over a radius of about 200 nautical miles.
8. United Nation Office of Outer Space Affairs

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1. ITU Recommendation ITU-R M.493-12 [↑](#footnote-ref-1)
2. For VHF DSC special cases bandwidth channels may be adjusted (12.5 Khz) or modulation scheme may enable data up to 9,600 bps (ITU Recommendation ITU-R M.1084-4) [↑](#footnote-ref-2)
3. IEEE standards 802.11 – a set of specifications for wireless local area networks (WLAN). [↑](#footnote-ref-3)