



Deliverable D1.11

Report on Future Digital Communications

Supporting document for D1.10 Digital Communications Strategy 2017-2030

Project no. 636329
Project acronym: EfficienSea2
EFFICIENSEA2 – efficient, safe and sustainable traffic at sea

Funding scheme: Innovation Action (IA)
Start date of project: 1 May 2015
End date of project: 30 April 2018
Duration: 36 months

Due date of deliverable: 01.05.2017
Actual submission date: 30.03.2017

Organisation in charge of deliverable: IALA

DOCUMENT STATUS

Authors

Name	Organisation
J Carson-Jackson	IALA
N Ward	IALA

Document History

Version	Date	Initials	Description
Initial v 1.0	05/01/2017	JACJ	
V2	06.03.2018	SD	Formating review

Review

Name	Organisation
Bjorn Pedersen	DMA

Executive Summary

The e-Navigation concept will increase the efficiency, safety and security of voyage planning and information in the maritime sector. e-Navigation is dependent on applications which provide mariners with the data they need in a more secure and efficient manner. These applications require communication technologies that can provide the necessary capacity for bidirectional ship-ship and ship-shore, including ship-satellite communication.

The vision for digital communications in the maritime environment is:

Secure, effective, seamless communications to support maritime applications.

To achieve the vision, four core strategic challenges have been identified:

1. Assessing operational requirements
2. Ensuring existing and developing digital maritime communications technologies interact effectively and seamlessly
3. Evaluating the suitability of different technologies to address the requirements
4. Providing communication options and implementing infrastructure to support digital maritime communications.

A number of response actions will be undertaken to address these core strategic challenges.

1 Requirements

- 1.1 Defining obligations for service provision (mandatory requirements)
- 1.2 Identifying preferred / additional services
- 1.3 Identifying geographic service area

2 Technologies

- 2.1 Identifying existing technologies and standards
- 2.2 Identifying developing technologies and standards
- 2.3 Identifying level of interaction between technologies
- 2.4 Confirming process to enable seamless communications

3 Suitability of Technology

- 3.1 Confirming range of candidate technologies
- 3.2 Matching candidate technologies to requirements

4 Infrastructure

- 4.1 Inventory of current / existing infrastructure and life-cycle maintenance cycles
- 4.2 Effectiveness of current / existing infrastructure
- 4.3 Identification of requirements for infrastructure to support new / developing technologies
- 4.4 Prioritising update / implementation of infrastructure.

Digital Communications in the Maritime Environment – 2013-2030

Vision - Secure, effective, seamless communications to support maritime applications.

SC 1 - Requirements

- 1.1 - obligations for service provision
- 1.2 - preferred or additional services
- 1.3 - geographic service area

SC 2 - Technologies

- 2.1 – existing technologies and standards
- 2.2 – new technologies and standards
- 2.3 – interaction between technologies
- 2.4 – seamless communications

SC 3 – Suitability of Technologies

- 3.1 – range of candidate technologies
- 3.2 – candidate technologies to address requirements

SC 4 - Infrastructure

- 4.1. – current infrastructure & lifecycle maintenance
- 4.2 – effectiveness of existing infrastructure
- 4.3 – requirements for changes
- 4.4 – prioritisation for changes

Ongoing – Develop, Approve, Monitor and Revise Strategy

Table of Contents

DOCUMENT STATUS	2
Authors	2
Document History	2
Review	2
Executive Summary	3
1 Introduction	8
1.1 Background.....	8
1.1.1 e-Navigation Solutions.....	9
1.1.2 Risk Control Options in e-Navigation.....	9
1.1.3 Maritime Service Portfolios	10
1.2 Scope and Objectives	10
1.3 Vision	11
1.4 Strategic Challenges	11
2 Strategic Challenge 1 - Operational requirements	12
2.1 User requirements summary.....	12
2.1.1 Sample use-cases	13
2.2 Areas of operation.....	15
2.3 Response	15
3 Strategic Challenge 2 – Technologies for digital communications	16
3.1 Candidate technologies.....	16
3.1.1 NAVDAT	17
3.1.2 VDES (including AIS, VDE and ASM)	18
3.1.3 Wi-fi	20
3.1.4 4G (4 th Generation).....	21
3.1.5 5G.....	21
3.1.6 Digital Selective Calling (DSC) (VHF, MF, HF).....	22
3.1.7 Digital Radio (VHF, HF) (other than DSC).....	23
3.1.8 Satellite.....	23
3.1.9 GEO Satellite Systems	24
3.1.10 LEO Satellite Systems	25
3.2 Comparison of communication technologies.....	27
3.3 Response	28



4	Strategic Challenge 3 - Suitability of Candidate Technologies.....	28
4.1	Evaluation of candidate technologies.....	30
4.1.1	No Go Area.....	30
4.1.2	Route Exchange	30
4.1.3	Navigation Warning	30
4.1.4	Weather Data	31
4.1.5	Telemedicine	31
4.1.6	Maritime Single Window	31
4.1.7	Search Plan	32
4.1.8	Passenger Internet Access.....	32
4.2	Response	32
5	Strategic Challenge 4 – Infrastructure.....	32
5.1	Common Shore-Based System Architecture.....	33
5.2	Maritime Cloud	33
5.3	Response	34
6	Implementing digital data communications strategy.....	34



List of Annexes

Annex A – Definitions and Acronyms	36
Annex B - References	39
Annex C – Application data size conversions.....	40
Annex D - Supporting communication systems inclusion justifications.....	41
Annex E - VDES channel applications	42
Annex F - Communication system capacity results	43

Tables

Table 1 – prioritised e-navigation solutions	9
Table 2 – Risk Control Options in e-Navigation.....	9
Table 3 - Maritime Service Portfolio, IMO e-navigation Strategic Implementation Plan	10
Table 4 – Requirements cross-referenced to the IMO SIP MSPs	13
Table 5 - Sample use cases and possible application requirements	14
Table 6: NAVDAT technical characteristics	17
Table 7: Channel allocation for VDES	19
Table 8: VDES technical characteristics	19
Table 9: Wi-Fi system characteristics	20
Table 10: 4G system characteristics.....	21
Table 11: 5G system characteristics.....	22
Table 12: DSC characteristics	22
Table 13: Digital VHF/HF system characteristics.....	23
Table 14: Inmarsat C technical characteristics	24
Table 15: Inmarsat Global Express system characteristics	25
Table 16: Iridium (Pilot) system characteristics	26
Table 17: Summary of communication technologies	27
Table 18: comparison of candidate technologies with sample use cases.....	29



Digital Communications in the Maritime Environment – 2017-2030

1 Introduction

In WP1 of EfficienSea 2, IALA leads Task 1.3: Coordinating standardization of solutions. IALA manages the work In Task 1.3, preparing reports and deliverables in conjunction with the other members of the Task Group (CIRM, UKHO).

The current environment for maritime navigation is complicated, unsynchronised and un-ergonomic. Navigational and communications equipment are not designed to specifically integrate with each other, creating difficulties which lead to frustrations for the mariner and can result in creating dangerous situations.

The International Maritime Organization (IMO) has developed the e-Navigation concept with a goal to improve safety, security and maritime efficiency. The e-Navigation concept recognises the key role of communications and has highlighted the requirement for effective digital networks to transfer data.

e-Navigation is defined as *“the harmonised collection, integration, exchange, presentation and analysis of maritime information on-board 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”*.

A goal of the introduction of e-Navigation is the integration of existing systems, and the evolution or development of new systems, that can facilitate more efficient voyages. This will be achieved through e-Navigation applications which benefit navigation or communication through electronic data transfer.

The focus for the strategy and implementation of digital communications technologies, and the provision of effective equipment and infrastructure is that the user will not be required to choose a candidate digital communications technology when transferring information; the system will choose the most appropriate means to transfer the data based on the technologies available and the parameters required for the data transmission.

The strategic plan to achieve this has been broke into short term (1-3 years); medium term (4-7 years) and longer term (8+ years)

1.1 Background

Digital communications are ubiquitous in our daily lives – both for work and for recreation. The introduction of ‘any-time, any-where’ access to information through the internet; text based or image based communications; geospatial locating and more is driving demand for faster, more robust, and more integrated, communication solutions.

Almost every e-Navigation solution currently 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, but it may be 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 carried out to better determine the data transfer requirements to address e-navigation elements and facilitate development of digital communications solutions for the maritime environment. This work provides a basis for analysis of candidate technologies and the opportunity to provide strategic guidance on implementation of the technologies in a rapidly changing maritime environment.

1.1.1 e-Navigation Solutions

While e-Navigation is a broad concept with many identified possible solutions, the IMO has developed a strategic implementation plan (SIP) which addresses five prioritized e-navigation solutions (Table 1):

Solution Reference #	Prioritized solution
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
S9	Improved communication of VTS Service Portfolio (not limited to VTS stations)

Table 1 – prioritised e-navigation solutions

Solutions S2, S4 and S9 focus on efficient transfer of marine information and data between all users (ship-ship; ship-shore; and shore-shore). To provide service on a global scale the information transfer requires both terrestrial and satellite services.

Solutions S1 and S3 promote workable and practical solutions for the use of information and data onboard. As such, the digital data exchange solution options must be complemented by standards for data reception and display.

1.1.2 Risk Control Options in e-Navigation

To support the development and implementation of the prioritized solutions, 7 risk control options (RCOs) have been identified (Table 2).

RCO Reference #	RCO
RCO 1	Integration of navigation information and equipment, including improved software quality assurance)
RCO 2	Bridge alert management
RCO 3	Standardized mode(s) for navigation equipment
RCO 4	Automated and standardized ship-shore reporting
RCO 5	Improved reliability and resilience of onboard PNT
RCO 6	Improved shore-based services
RCO 7	Bridge and workstation layout standardization

Table 2 – Risk Control Options in e-Navigation

The RCOs highlight the technical developments inherent in navigation, and are underlined by a need to facilitate data transfer using systems and technologies that are robust, comprehensive, secure and future proof. Standardization of bridge layout, data transfer

formats and information displays is also highlighted in the RCOs. The implementation of digital communications must integrate these fundamental elements.

1.1.3 Maritime Service Portfolios

While the purpose of e-Navigation is to enhance berth-to-berth navigation and related services for safety and security at sea and protection of the marine environment, it also seeks to enhance maritime safety through simplification and harmonization of information and to facilitate and increase efficiency of maritime trade and transport by improved information exchange. Building on the higher-level solutions, and taking into account the risk control options, a number of specific Maritime Service Portfolios' (MSP) have been developed. (Table 3)

MSP reference	Service
MSP 1	VTS Information Service (IS);
MSP 2	VTS Navigation Assistance Service (NAS)
MSP 3	VTS Traffic Organization Service (TOS)
MSP 4	Local Port Service (LPS)
MSP 5	Maritime Safety Information (MSI) service
MSP 6	pilotage service
MSP 7	tugs service
MSP 8	vessel shore reporting
MSP 9	Telemedical Maritime Assistance Service (TMAS)
MSP 10	Maritime Assistance Service (MAS)
MSP 11	nautical chart service
MSP 12	nautical publications service
MSP 13	ice navigation service
MSP 14	Meteorological information service
MSP 15	real-time hydrographic and environmental information services
MSP 16	Search and Rescue (SAR) Service

Table 3 - Maritime Service Portfolio, IMO e-navigation Strategic Implementation Plan

The development of a digital communications strategy supports, and builds on, the work undertaken for e-Navigation and the many related projects to assess the implementation of e-Navigation solutions.

1.2 Scope and Objectives

Digital Communications in the Maritime Environment identifies communications to support maritime activities, noting the requirements identified through work carried out by various international organisations in the development of the IMO e-Navigation strategy implementation plan (SIP). This document provides detail on the requirements; candidate solutions; and proposed suitability for the solutions to address the requirements.

This document is intended to guide the future development and implementation of e-Navigation solutions ashore and afloat. It will be reviewed and revised as technology develops and requirements change, with the overall focus on addressing the prioritized communications solutions (S2, S4, and S9) within the framework of the RCOs as identified through the IMO e-Navigation development process.

1.3 Vision

The vision for digital communications in the maritime environment is:

Secure, effective, seamless communications to support maritime applications.

1.4 Strategic Challenges

To achieve the vision, four core strategic challenges have been identified:

1. Assessing operational requirements
2. Ensuring existing and developing digital maritime communications technologies interact effectively and seamlessly
3. Evaluating the suitability of different technologies to address the requirements
4. Providing communication options and implementing infrastructure to support digital maritime communications.

Each of these challenges have a number of implications and actions which are detailed within this document.

A number of response actions will be undertaken to address these core strategic challenges.

1 Requirements

To confirm requirements, the following actions will be undertaken:

- 1.4 Defining obligations for service provision (mandatory requirements)
- 1.5 Identifying preferred / additional services
- 1.6 Identifying geographic service area

2 Technologies

When the service requirements are clearly identified, it will then possible to identify the preferred candidate technologies and verify existing interaction between technologies to achieve seamless communications capabilities. The response actions for technologies are:

- 2.1 Identifying existing technologies and standards
- 2.2 Identifying developing technologies and standards
- 2.3 Identifying level of interaction between technologies
- 2.4 Confirming process to enable seamless communications

3 Suitability of Technology

It is now possible to link the technology(ies) to the requirements, verifying the range of application and approaches to ensure technology(ies) address the requirements.

- 3.1 Confirming range of candidate technologies
- 3.2 Matching candidate technologies to requirements

4 Infrastructure

Matching candidate technologies and service requirements, it becomes possible to prioritise efforts when adapting and adopting enhanced digital data communications. The following will be considered:

- 4.1 Inventory of current / existing infrastructure and life-cycle maintenance cycles
- 4.2 Effectiveness of current / existing infrastructure
- 4.3 Identification of requirements for infrastructure to support new / developing technologies

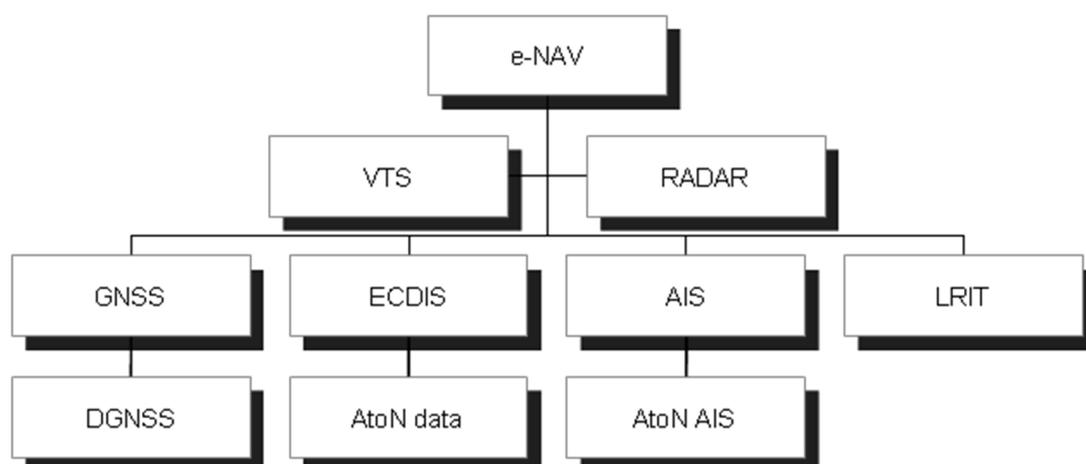
4.4 Prioritising update / implementation of infrastructure.

2 Strategic Challenge 1 - Operational requirements

The development of effective, and efficient data transfer mechanisms through digital means has seen an explosion of information transfer opportunities. While there are increasing opportunities to ‘be connected’ through digital networks, these may not enable the transfer of information in a common, readable format and may not include any aspects to ensure accuracy, reliability and security of the data transfer.

The e-Navigation Solutions and Risk Control Options highlight the requirement for a comprehensive, robust, efficient and secure means to communicate information both afloat and ashore. The e-Navigation concept is foreseen to be supported by a host of current and new navigation, communication and surveillance technologies (Figure 1).

Figure 1: Overview of e-Navigation technologies



2.1 User requirements summary

There are a number of user requirements related to each e-Navigation application that, when met, will support the full potential of the applications; these requirements include the type of data to be exchanged, the area in which the application is to be used, and the latency and reliability of the data exchanged.

There are a number of mandatory communications capabilities to support search and rescue, enable interaction to facilitate safe and pollution free transits, or enable efficient vessel movements within a port or waterway environment.

In addition, there are additional services which enhance the overall safe, secure, efficient and pollution free transits of vessels. Seven high-level use cases have been identified, which reflect the MSP developments. (Table 4)

Use Case	MSP Reference
1. SAR Communications	MSP 9 - Telemedical Maritime Assistance Service (TMAS) MSP 16 - Search and Rescue (SAR) Service
2. Maritime Safety Information	MSP 5 - Maritime Safety Information (MSI) service MSP 13 - Ice navigation service MSP 14 - Meteorological information service MSP 15 - Real-time hydrographic and environmental information services

Use Case	MSP Reference
3. Ship Reporting	MSP 8 - Vessel shore reporting MSP 15 - Real-time hydrographic and environmental information services
4. Vessel Traffic Services	MSP 1 - VTS Information Service (IS) MSP 2 - VTS Navigation Assistance Service (NAS) MSP 3 - VTS Traffic Organization Service (TOS); MSP 4 - Local Port Service (LPS) MSP 6 - Pilotage service MSP 7 - Tugs service
5. Charts and Publications	MSP 11 - Nautical chart service MSP 12 - Nautical publications service MSP 15 - Real-time hydrographic and environmental information services
6. Route Exchange	MSP 1 - VTS Information Service (IS) MSP 2 - VTS Navigation Assistance Service (NAS) MSP 3 - VTS Traffic Organization Service (TOS); MSP 4 - Local Port Service (LPS) MSP 5 - Maritime Safety Information (MSI) service MSP 6 - Pilotage service MSP 7 - Tugs service MSP 8 - Vessel shore reporting MSP 10 - Maritime Assistance Service (MAS) MSP 11 - Nautical chart service MSP 12 - Nautical publications service MSP 13 - Ice navigation service MSP 14 - Meteorological information service MSP 15 - Real-time hydrographic and environmental information services MSP 16 - Search and Rescue (SAR) Service
7. Logistics	MSP 7 - Tugs service MSP 8 - Vessel shore reporting

Table 4 – Requirements cross-referenced to the IMO SIP MSPs

2.1.1 Sample use-cases

To provide proposed data sets around the digital transfers, the following provides a summary of sample use-cases for different applications. This work forms the basis for the analysis of candidate digital data communications systems (Table 5).

Use Case	Application	Max single message size (bits)		Safety critical	Effects of delay (Low – delay acceptable; High – unacceptable)
		Vessel tx	Shore tx		
2 - Maritime Safety Information	No-Go area	400	20,000,000	Yes	Medium - as data includes a 48 hour forecast, a delay doesn't necessarily have a significant impact. However, as this provides distinct areas of non-

Use Case	Application	Max single message size (bits)		Safety critical	Effects of delay (Low – delay acceptable; High – unacceptable)
		Vessel tx	Shore tx		
					navigable areas, it is critical that the data is received by the vessel.
4 - VTS 6 - Route Exchange	In both VTS and non VTS areas	880		No	Low - useful information to have but not critical. Mariner is still required to look out the window as a requirement for collision avoidance.
2 - Maritime Safety Information	Navigation warning (i.e. ship wreck)	320	2,400	Yes	Medium to High - safety information required for voyage, however a slight delay will not largely increase the risk. A long delay could be critical due to the importance of messages such as ship wreck and bad weather warnings.
2 - Maritime Safety Information	Weather Data	20,800	276,480	No	Low - the most critical weather messages will be provided in the form of an MSI/NM. Therefore this application will be used for additional non-critical data, supplementing the MSIs.
1 - SAR Communications	Telemedicine	1,000,000 per second (video link) 1,760,000 (total, biomedical records)	1,000,000 per second (video link)	Yes	High - communication between ship and shore must not be degraded due to the critical nature of the application.
3 - Ship Reporting 7 - Logistics	Maritime Single Window	240,000		No	Low - must be carried out at least 24 hours prior to entry to port, so timescales indicate a delay of seconds or minutes will not be an issue.
6 - SAR Communications	Provision of search plan		1,100	Yes	High - due to the safety of life nature of this application, the data should not be subject to any delays.
7 - Logistics	Passenger Internet Access	12,000 (per second)	800,000 (per second)	No	Low - purely commercial application. Passenger frustration if delayed, but not necessary for safety.

Table 5 - Sample use cases and possible application requirements

2.2 Areas of operation

A goal of e-Navigation is to provide new capabilities for both ship operations and shore operations, and the interaction between ship and shore.

For ship operations e-Navigation is focused on an integrated and consistent approach to support the mariner, with a focus on human-centred design. The key is to ensure systems benefit from integration with the ship's own sensors, accept and make use of supporting information, work within a standard user interface, and provide tools that support a comprehensive system for managing guard zones, alerts, and other aspects of operation.

Making use of core technologies¹, e-Navigation notes the requirement to actively engage the mariner in the process of navigation while preventing distraction and information overload. The operational focus is on timely, accurate and appropriate provision of information.

On the shore side the management of vessel traffic and related services will be enhanced through better provision, co-ordination, and exchange of comprehensive data in formats that will be more easily understood and utilised by shore-based operators in support of vessel safety and efficiency. This is perceived as a major commercial benefit by port operators.

Within the work on e-Navigation the IMO have identified six areas for the delivery of the MSPs. These are:

1. port areas and approaches;
2. coastal waters and confined or restricted areas;
3. open sea and open areas;
4. areas with offshore and/or infrastructure developments;
5. Polar areas; and
6. other remote areas.

2.3 Response

To confirm requirements for digital communications in the maritime environment, it is recommended that the following be addressed:

What are the obligations for service provision?

- For example: obligations to provide information as signatory to IMO conventions, under the World Wide Radio Navigation Service, etc.

What are the preferred / additional services to be provided?

- For example: vessel arrival / slot arrival systems; vessel traffic services; logistic services, etc.

What is the geographic area for service provision?

- For example: extend of territorial sea / exclusive economic zone; within traffic separation systems; within port confines

The activities that will be undertaken to address strategic challenge 1 – Operational Requirements – will include:

- 1.1 Defining obligations for service provision (mandatory requirements)
- 1.2 Identifying preferred / additional services
- 1.3 Identifying geographic service area

¹ Core technologies include: high integrity electronic positioning (e.g. dual constellations for GNSS with a terrestrial back-up); electronic navigational charts (ENC); accurate positional data for own ship and other ships; position fixing methods that seamlessly integrate with navigation and communications systems.

3 Strategic Challenge 2 – Technologies for digital communications

There are a number of candidate communication technologies that could support the 7 high level use cases and the supporting applications. Each communication technology has characteristics such as data capacity, data rates and channels, as well as benefits and drawbacks of using the system (pros and cons).

The communication technologies identified here represent systems that are currently being used, developed or assessed by the maritime community. Looking ahead at the role of digital communications, the technologies exclude those that are expected to become obsolete or be replaced in the near to medium term (5-10 years).

Communications technologies, either not currently considered or under development, which may also be suitable for supporting e-Navigation applications within 5-10 years are also included.

3.1 Candidate technologies

The list of candidate communication technologies is presented below. A full list of communication technologies included in the analysis with their justification for inclusion is provided in Annex D.

- **NAVDAT:** this system is a development on 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, developed to meet the increasing need for data communication between maritime users and due to the significant rise in VHF data link load with the increasing use of AIS. 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, HF and MF. The system uses maritime mobile service identities and enables direct transmission or group / area transmissions of basic data.
- **Digital VHF and HF:** Digital VHF and 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 VHF and HF will enable the exchange of digital data messages.
- **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 within a port or harbour environment.
- **4G:** a mobile telecommunications standard supporting mobile internet broadband, succeeding 3G. Provides mobile broadband with data rates of 100s of Mbps for mobile users. Systems falling under the 4G standard include WiMAX and LTE.
- **5G:** planned evolution of 4G, with data rates expected to be 1 Gbps and an intended delivery year of 2020.
- Satellite communication systems and services including:
 - Inmarsat Global Express – 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 K_a band with global coverage.

- 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 Service (GMDSS).
- Iridium – LEO satellite constellation. Existing low-earth orbiting communications, providing voice and limited internet access.

3.1.1 NAVDAT

NAVTEX is a direct-printing service for delivery of navigational and meteorological warnings and forecasts, as well as urgent marine safety information. NAVTEX is currently used as part of the Global Maritime Distress Safety System (GMDSS) and is mandated to be carried by certain classes of SOLAS vessels.

NAVDAT is a development of the NAVTEX system. The NAVDAT system will provide much greater data rates than the current NAVTEX system, with higher capacity. While NAVTEX is based only on text data transfers, NAVDAT will introduce the possibility to transfer both image (e.g. isobaric charts) and graphical data. This will enable the provision of images or graphics – for example providing a graphic plot of the eye of the hurricane with projected motion; the positions of icebergs and other maritime information. NAVDAT could also support the transmission of Search and Rescue information, piracy warnings and distress and emergency messaging.

Similar to NAVTEX, NAVDAT will be used as a shore-ship communications system, with coast stations providing the relevant information to vessels within their region.

3.1.1.1 Characteristics

Table 6 presents the key technical characteristics of NAVDAT.

System	Frequency (kHz)	Bandwidth (kHz)	Data Rate	Equipment
NAVDAT	500	10	12-18 kbps	NAVDAT receiver and appropriate antenna

Table 6: NAVDAT technical characteristics

3.1.1.2 Benefits

The benefits of the NAVDAT system include:

- additional data transfer types;
- graphical data transmission - enables the mariners to get an accurate and clear reflection of the issues on their intended route.
- Fast data transfer – theoretical 25 kbps (over 200 times faster than NAVTEX) with expected achievable rate of 12-18 kbps (approximately 100 times faster than NAVTEX).
- Broadcast options – to selected ships in a geographic area or specific ships to ensure information received is relevant (i.e. ships in a fleet; all fishing vessels in an area)
- Data integrity – enables data encryption for transmission of confidential information
- Frequency allocation (500 kHz, 10 kHz bandwidth) - within the maritime sector, with minimum interference from / to other applications.

3.1.1.3 Implications

For NAVDAT operation:

- vessels will need to have NAVDAT receiver (including HMI and integration) and the appropriate antenna.
- Shore stations need to provide NAVDAT service with transmitter/receiver capability, HMI / integration with other shore technologies; and appropriate antenna.

3.1.2 VDES (including AIS, VDE and ASM)

The Automatic Identification System (AIS) provides an effective means to transfer digital data. In addition to the initially intended purpose of providing vessel positional and related information in support of VTS and 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.

The VHF Data Exchange System (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 incorporates the existing AIS within the system; provides for 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 ability to access the polar regions. VDE-S is under development, with studies to be provided to the World Radio Conference in 2019.

The 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. New techniques providing higher data rates than those used for AIS is a core element of VDES. Furthermore, VDES network protocol is optimized for data communication so that each VDES message is transmitted with a high confidence of reception.

The key concept of operation of the VDES includes:

- The VDES provides a capability of data exchange between ships and shore users by terrestrial or satellite link.
- Data exchange from the ship may occur automatically or manually.
- Data exchange uses the designated VHF channel(s).
- Transmission and reception of the data occurs with the minimum involvement of ship's personnel.
- The VDES includes existing AIS applications.
- The VDES includes existing ASM.
- VDES additional capabilities include support of the VHF Data Exchange (VDE).
- The VDES related applications should support language independent communications (e.g. through the use of a digital data dictionaries).
- The VDES implements data integrity monitoring at the VDES link level (e.g. check sum).
- The VDES related applications address cyber security (e.g. authentication, key management and, if required, encryption).
- The VDES has a high level of availability.
- The VDES supports machine-to-machine communications (for example, interfaces with external equipment providing applications related to VDES).
- The VDES related applications enable clear comprehension of the information sent / received through the VDES.

3.1.2.1 Characteristics

Table 7 identifies the frequency allocation for VDES, including those proposed for VDE-S. A table listing the channels against their application is given in Annex E.

Table 8 presents the key technical characteristics of VDES.

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 (87B)	161.975	161.975
AIS 2 (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)	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)
24	157.200 (1024)	161.800 (2024)
84	157.225 (1084)	161.825 (2084)
25	157.250 (1025)	161.850 (2025)
85	157.275 (1085)	161.875 (2085)
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)
26	157.300 (1026) VDE 2, SAT Up3	161.900 (2026) (SAT 1)
86	157.325 (1086) VDE 2, SAT Up3	161.925 (2086) (SAT 1)

Table 7: Channel allocation for VDES

System	Frequency	Bandwidth	Data Rate
VDES ASM	As above	25 kHz	9.6 kbps
VDES VDE	As above	100 kHz (merged channels)	306 kbps

Table 8: VDES technical characteristics

3.1.2.2 Benefits

The benefit of the VDES include:

- AIS channels are protected for originally intended purpose, as state in SOLAS Chapter V

- safety information is provided on VDE and ASM (as appropriate) channels which frees up the AIS channels
- additional data transfer types;
- text and graphical data transmission - enables the mariners to get an accurate and clear reflection of the issues on their intended route.
- Fast data transfer – theoretical rate of up to 306 kpbs
- Data integrity – could enable data encryption for transmission of confidential information
- Potential global coverage with VDE-S.
- VDE channels have the ability to be merged to increase bandwidth from 25 kHz to 50 kHz or 100 kHz.

3.1.2.3 Implications

For VDES operation:

- vessels will need to have a VDES transmitter / receiver capability (including HMI and integration) and the appropriate antenna. AIS is integral to VDES. There will need to be a transition period with AIS / VDE / ASM implementation.
- Shore stations need to update AIS shore service with VDES transmitter/receiver capability, HMI / integration with other shore technologies; and appropriate antenna.
- VDES will require installation of software definable radios (SDRs) which enables the grouping of spectrum.

3.1.3 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)² 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 provides 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.

3.1.3.1 Characteristics

Table 9 presents the key characteristics of Wi-Fi.

System	Frequency	Bandwidth	Data Rate
Wi-Fi 802.11ac	5 GHz	40 MHz	Up to 1.3 Gbps

Table 9: Wi-Fi system characteristics

The IEEE 802.11ac 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 is likely to experience interference.

3.1.3.2 Benefits

The benefit of Wi-Fi include:

- text and graphical data transmission - enables the mariners to get an accurate and clear reflection of the issues on their intended route.
- Fast data transfer – theoretical rate of up to 1.3 Gbps

² IEEE standards 802.11 – a set of specifications for wireless local area networks (WLAN).

- Data integrity – could enable data encryption for transmission of confidential information

3.1.3.3 Implications

For Wi-Fi operation:

- vessels will need to have access to Wi-Fi with service provider / 'hot spot' to access internet.
- Limited range for Wi-Fi coverage with internet access
- Vessels can have internal Wi-Fi to support ship operations
- Shore stations access internet (existing)

3.1.4 4G (4th Generation)

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 leading a major provider, Sprint, to decommission networks in some countries. In contrast, LTE (long term evolution) is widely used, with the more recent development, LTE-Advanced, regarded as a fully compliant 4G network.

3.1.4.1 Characteristics

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

Table 10 presents the key characteristics of LTE-Advanced.

System	Frequency	Bandwidth	Data Rate
4G – LTE Advanced	2.6 GHz	20 MHz	600 Mbps (download)

Table 10: 4G system characteristics

3.1.4.2 Benefits

The benefits of 4G / LTE-Advance include:

- text and graphical data transmission - enables the mariners to get an accurate and clear reflection of the issues on their intended route.
- Fast data transfer – theoretical rate of up to 600 Mbps (download)
- Data integrity – could enable data encryption for transmission of confidential information

3.1.4.3 Implications

For 4G / LTE-Advance operation:

- Vessels will need to have access to 4G / LTE-Advance
- Range limited by network coverage, generally populated land areas
- Shore stations need to arrange access to 4G / LTE-Advance.

3.1.5 5G

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.

3.1.5.1 Characteristics

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 11 provides the technical characteristics for 5G.

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

Table 11: 5G system characteristics

3.1.5.2 Benefits

The benefits of 5G are expected to include:

- text and graphical data transmission - enables the mariners to get an accurate and clear reflection of the issues on their intended route.
- Fast data transfer – theoretical rate of up to 1.2 Gbps (download)
- Increased capacity
- Data integrity – could enable data encryption for transmission of confidential information

3.1.5.3 Implications

For 5G operation:

- Vessels will need to have access to 5G
- Range limited by network coverage, generally populated land areas
- Shore stations need to arrange access to 5G.

3.1.6 Digital Selective Calling (DSC) (VHF, MF, 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 (rather like a telephone number) or send a signal to vessels in the area – for example when sending a Distress/Urgency call.

3.1.6.1 Characteristics

Table 12 presents the key characteristics of DSC.³

System	Frequency	Bandwidth	Data Rate
DSC	22187.5, 4207.5, 6312.0, 8414.5, 12577.0, and 16804.5 (kHz)	VHF – 25 kHz	VHF – 1,200 bps ⁴
	156.525 MHz	HF – bandwidth constrained by SSB modulation scheme	HF – 300 bps

Table 12: DSC characteristics

³ ITU Recommendation ITU-R M.493-12

⁴ 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)

3.1.6.2 Benefits

The benefits of DSC include:

- text data transmission with distress alerting capability.
- Individual or group addressed transmissions
- Ability to acknowledge receipt.

3.1.6.3 Implications

For DSC operation:

- Vessels must be equipped with DSC equipment (required under SOLAS, voluntary for other vessels)
- Range limited by coverage – limited for VHF, more extensive for MF / HF.
- Shore stations must implement DSC equipment.

3.1.7 Digital Radio (VHF, HF) (other than DSC)

VHF and HF systems are commonly used worldwide in maritime for general voice communication, transmission/reception of distress and safety information, and reception of urgent marine information broadcasts. Other than digital selective calling (DSC – section X refers), these systems are 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. An example is the VHF Data Exchange System (VDES – section 3.1.2)

Digital systems should enable full duplex communications, higher data rates and more efficient use of spectrum while maintaining or improving on the current operational ranges for high quality voice, all within the existing spectrum used by VHF and HF systems.

3.1.7.1 Characteristics

Although there are competing technologies, the characteristics and capabilities are broadly similar. The focus is on changes to the over-the-air protocol rather than making fundamental changes in the architecture of existing VHF and HF mobile radio networks. In Europe, there is a new European Standard for Digital Mobile Radio (DMR). The DMR operates within the existing 12.5 kHz channel spacing achieving two channels through two-slot TDMA. Voice transmissions are encoded using the AMBE+2 codec⁵. Features supported include fast call set-up, calls to groups and individuals, and short data and packet data calls. The communications modes include individual calls, group calls and broadcast calls. Other important DMR functions supported include emergency calls, priority calls, full duplex communications, short data messages and IP-packet data transmissions.

Table 13 provides the technical characteristics for digital VHF/HF.

System	Frequency	Bandwidth for a simplex channel	Data Rate
Digital VHF/HF	136-174, 400-470, 450-520 MHz	6.25 kHz	4.8 kbps

Table 13: Digital VHF/HF system characteristics

3.1.8 Satellite

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 services are provided from both geostationary (GEO) satellites and low earth orbiting (LEO) satellites.

GEO satellites operate at an altitude of 35,786 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. These satellites

⁵ AMBE +2 codec is a current version of vocoder - voice encoder/decoder. The vocoder is the function within a digital radio that converts an analogue speech signal into a digital bit stream.

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°).

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, store and forward.

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.

3.1.9 GEO Satellite Systems

3.1.9.1 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 and is design 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.

3.1.9.1.1 Characteristics – Inmarsat C

The 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 14 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 14: Inmarsat C technical characteristics

3.1.9.1.2 Benefits – Inmarsat C

The benefits of Inmarsat C include:

- text data transmission.
- Stable, if slow, data transmission
- Data integrity – could enable data encryption for transmission of confidential information.

3.1.9.1.3 Implications – Inmarsat C

For Inmarsat C operation:

- Vessels will need to install an Inmarsat terminal (receive / transmit) with associated antenna

- Shore stations need to install an Inmarsat terminal (receive / transmit) and arrange access through a service provider

3.1.9.2 Inmarsat GX

Inmarsat Global Express (GX) is the latest satellite service offering from Inmarsat providing higher bandwidth than the existing Inmarsat SwiftBroadband and FleetBroadband services. 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 interference.

3.1.9.2.1 Characteristics - Inmarsat GX

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 15 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 15: Inmarsat Global Express system characteristics

3.1.9.2.2 Benefits – Inmarsat GX

The benefits of Inmarsat GX include:

- Text data and graphic transmission.
- Higher rates, enables internet access
- Data integrity (could enable data encryption for transmission of confidential information)

3.1.9.2.3 Implications – Inmarsat GX

For Inmarsat GX operation:

- Vessels will need to install an Inmarsat terminal (receive / transmit) with associated antenna
- Shore stations need to install an Inmarsat terminal (receive / transmit) and arrange with a service provider for access to a land-user terminal (LUT)
- No coverage in polar regions / limited coverage between 70 and 76 degrees latitude.

3.1.10 LEO Satellite Systems

3.1.10.1 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.

3.1.10.1.1 Characteristics - Iridium

The Iridium satellite system uses L band transponders to communicate with the ground based users with frequencies in the band 1616 - 1626.5 MHz providing up to 134 kbps bidirectional (OpenPort broadband service)

Table 16 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 16: Iridium (Pilot) system characteristics

3.1.10.1.2 Benefits – Iridium

The benefits of Iridium include:

- Text data and voice calls.
- Data rates can enable limited internet access
- Data integrity (could enable data encryption for transmission of confidential information)
- Global coverage (including polar regions)

3.1.10.1.3 Implications - Iridium

For Iridium (Pilot) operation:

- Requirement to purchase specific equipment with access (contract)
- Coverage is not persistent

3.2 Comparison of communication technologies

Table 17 provides a summary matrix outlining the communication technologies.

Communication Technology	Data rate	Infrastructure	Coverage	Maritime / public
NAVDAT	12-18 kbps	Based on NAVTEX	250/300NM	Maritime
VDES VDE	307 kbps	VHF Data link, RR Appendix 18 channels	Line of sight, approx 15NM-65NM Satellite component provides further coverage	Maritime
VDES ASM	9.6 kbps	VHF Data link, RR Appendix 18 channels	Line of sight, approx 15NM-65NM	Maritime
Wi-Fi (IEEE 802.11ac)	1,300 kbps	Routers/Access points	50m	Public
Digital VHF	4.8 kbps	Base station/mobile radios	Line of sight, approx 15NM-65NM	Maritime
4G	600 Mbps	4G Base stations	5-30km	Public
5G	1,200 Mbps	5G base stations	5-30km	Public
Inmarsat C	600 bps	Satellite service	Global, spot beams	Maritime
Inmarsat GX	50 Mbps	Satellite functioning on Ka band	Global, spot beams	Cross Industry
Iridium	Up to 134 kbps	Satellite functioning on L band	Global	Cross Industry (Iridium Pilot Maritime)

Table 17: Summary of communication technologies

From Table 17 it can be seen that the communication technologies identified to support e-Navigation provide varied performance and attributes.

GEO satellite systems, such as the Inmarsat satellites, provide coverage to a global market and therefore can be considered for applications where data is required to be transmitted further afield. This is a similar case for LEO satellite systems such as Iridium and Orbcomm, however limitations on communication is related to the orbital plane of the satellites and the size of the constellation. Most of the communication technologies' capabilities are driven by their land based infrastructure, making coverage at sea more difficult. NAVDAT uses the current infrastructure from NAVTEX, but does provide a larger coverage region. There are limitations for areas where NAVTEX has not been implemented, with a need to install additional shore infrastructure to support NAVDAT. Both 4G and 5G have limited range from their base stations, covering the shore element effectively but with very limited range event within some port limits. Wi-Fi is limited to an even smaller range than 4G/5G services.

To address the need to transfer images, NAVDAT and VDES are well placed to deal with these types of messaging, with NAVDAT available to broadcast as well as providing multicast and unicast transmissions. Furthermore, with a range of 300NM, a large number of vessels can be reached and with an expected data rate of 12-18 kbps, this provides a rate over 300 times faster than NAVTEX. Alternatively, the availability of merging channels within the VDES system provides a larger bandwidth to transfer data, making it a viable option for the large message size. With the full system implementation for VDES there will be opportunity to provide global service, within the limitations of a LEO satellite system. The terrestrial range for VDES can be expected to be similar to AIS,

dependant on the height of the transmitting and receiving antennae as well as changes in propagation.

The mobile data standards 4G and 5G provide the highest data rates out of all of the candidate communication technologies. However, these are designed primarily for providing mobile internet broadband and are limited by their range. The typical range of a high powered mobile base station providing a macro cell is approximately 30km (16 nautical miles) while still providing reliable data rates. Greater ranges are possible but the achieved data rates may be reduced. These are also public networks with significant demand from outside the maritime industry. These systems are best placed to provide internet connections close to the shore and within a port. The broadband satellite service Inmarsat Global Express does not provide the data rates that the 4G and 5G networks can provide, however the coverage range is a major advantage for this service.

3.3 Response

To identify the most appropriate candidate communication technology(ies) for digital communications in the maritime environment, the following actions will be undertaken:

- 2.5 Identifying existing technologies and standards
- 2.6 Identifying developing technologies and standards
- 2.7 Identifying level of interaction between technologies
- 2.8 Confirming process to enable seamless communications

4 Strategic Challenge 3 - Suitability of Candidate Technologies

While many of the candidate technologies could be capable of addressing the sample use cases, some are more effective than others. The challenge is to identify the most appropriate technology which addresses the requirement and area of operation.

Based on the criticality of reception, time taken to transmit (based on peak demand), the size of the data packet and the area of operations, proposed candidate technologies are presented in Table 18. This also takes into account the channel usage (i.e. reserved or public), and the type of service provided by the communication technology application.

Digital communications in the maritime environment – 2017 - 2030

Use Case	Application	Candidate technology									Comments	
		NAVDAAT	VDES	DSC VHF / HF	digital VHF / HF	WI-Fi	4G	5G	GEO Sat	LEO Sat		
2 - Maritime Safety Information	No-Go area		X - P				X	X				Demanding application – requires high throughput in all areas.
4 - VTS 6 - Route Exchange	In both VTS and non VTS areas		X - P				X	X				Low data application, includes ship-ship. May be within 4G/5G coverage area.
2 - Maritime Safety Information	Navigation warning (i.e. ship wreck)	X - P	X - P		X	X	X	X	X	X		Majority of systems could support some aspects of MSI. Criticality, location and data packet size will dictate preferred approach.
2 - Maritime Safety Information	Weather Data	X	X - P							X		Potentially data intense application, but could vary.
1 - SAR Communications	Telemedicine		X		X		X - P	X - P	X - P			Potentially data intense, could require voice, video and images.
3 - Ship Reporting 7 - Logistics	Maritime Single Window Reporting		X - P			X - P	X - P	X - P	X	X		Initial information set could be quite large, updates smaller data packets.
6 - Route Exchange 7 - Logistics	Provision of Search Plan	X - P	X - P						X			Low data application.
7 - Logistics	Passenger Internet Access						X - P	X - P	X - P			Demanding data application, not critical to safety of operations.

Table 18: comparison of candidate technologies with sample use cases

X – candidate technology capable of addressing requirements

P – preferred candidate technology – with use dependant on area of operation

4.1 Evaluation of candidate technologies

Table 18 is based on an analysis of how the communication systems satisfy the application requirements. When assessing the suitability of communication systems, both a ratio of the average application load (kbps) to the theoretical capacity of the communication system, and the time taken, in seconds, to serve the peak application data load (kb), were taken into consideration. The concept of 'peak load' is included, noting that this represents a theoretical maximum based on all users making data demands at the same time. In practice this is very unlikely to happen but the peak load calculation still serves as a useful way of assessing the relative ability of communication systems to support peaks in demand.

The details below are based on the results of e-Navigation Communication Requirements Study, carried out by the General Lighthouse Authorities in 2015.

4.1.1 No Go Area

The No Go area is a demanding application data wise as it requires a high throughput of data. When the average and peak loads were assessed, it was found that the average load from the application could be supported by a number of communication systems i.e. most ratios were low. However, the only communication systems to easily support the peak demand (less than a second to service the peak data demand), were the 4G and 5G networks. The VDES was the next best system, providing the peak demand in a few minutes.

The coverage range of the 4G and 5G networks is limited and it would not be feasible to support the vessel away from shore. Despite the peak value for VDES indicating a transmitting time of minutes, in reality this is likely to be less as not all ships will be transmitting the data at the same time. Coupled with the requirement that the data does not need to be instantaneous, this leads to the conclusion that VDES would be best suited to supporting the No Go Area application.

Preferred Technology (ies): VDES

4.1.2 Route Exchange

Route Exchange relies on the transfer of waypoints with some possible additional text data and was found to be a low data application. This meant that a number of systems had the capabilities to support the applications. Even at peak demand, the majority of communication systems would take less than a second to service this demand. The application does not necessitate the need for ship-ship, as well as ship-shore and shore-ship, communication. As the VDES AIS channels are designed for ship-ship, ship-shore and shore-ship communication and the position reporting style of the data file that the application transmits, VDES is best suited to supporting the application.

Preferred Technology (ies): VDES

4.1.3 Navigation Warning

Navigation Warnings could be text based or include some graphic information. For the purpose of this review it has been considered as a text based, relatively low data application. Although the majority of systems could support the average load for the navigation warnings (part of maritime safety information), only a couple of systems support the peak load: the NAVDAT system would service a peak in the order of seconds, whilst for the VDES it would be less than a second. However, navigation warnings are critical to the safety of a vessel's voyage and 4G / 5G would do not provide service away from shore.

Although a delay in MSI is not ideal, a delay in the order of seconds may be acceptable. As the peak load in reality is not likely to reach the calculated peak load (due to the improbability of all vessels requesting at once), this leads to the conclusion that both NAVDAT and VDES would support the application. Noting NAVDAT is a shore-ship only communication for ship-ship or ship-shore communication VDES would be preferred.

Preferred Technology (ies): NAVDAT (just MSI response), VDES (both request, and MSI response)

4.1.4 Weather Data

Weather Data is potentially a data intense application. With weather information available 54 hours into the future and noting the high demand for information during significant weather event, the peak data demand is potentially large (if a number of ships request the weather data at the same time). Peak demand could only realistically be supported by the Inmarsat GX system or VDES as these systems would be able to service the peak demand in the region of seconds. These systems also provide good coverage.

Considering the low likelihood that a vessel would request the full 54 hour forecast (as not all vessels' voyages would last that long), the peak data packet is realistically likely to be smaller than theoretically calculated. This therefore reduces the expected delay the communication systems would produce. Furthermore, a delay in the magnitude of seconds is acceptable for the Weather Data application.

Inmarsat GX is not restricted to the maritime industry and other users will be utilising this link which would reduce the available bandwidth and increase the time delay. For this reason, the best application for supporting the weather data application is VDES.

Preferred Technology (ies): VDES

4.1.5 Telemedicine

The telemedicine application requires high quality video and audio transmission, both ways (ship-shore and shore-ship). This therefore means that only high bandwidth systems are able to serve the application. This limits the possible communication systems to 4G, 5G, Wi-Fi and Inmarsat GX.

However, as the telemedicine application may be needed at any point of the voyage, the 4G and 5G coverage will not be sufficient to provide a trustworthy link should the vessel be far away from shore. This therefore would indicate that the Inmarsat GX system would be best placed of the communication systems to support the applications.

Preferred Technology (ies): 4G & 5G (close to shore), Inmarsat GX (away from shore)

4.1.6 Maritime Single Window

The Maritime Single Window application is used infrequently by vessels as it only consists of one submission of data to a 'single window' per journey. However, the data package is potentially large when it is initially sent. There may be updates to the information sent throughout the voyage, which could be part of a slot-arrival or vessel arrival system.

The data sent to the portal (the 'single window') is required more than 24 hours in advance of arrival to a port, and therefore the effect of a small delay is not critical to the application.

Analysing the time delays that would be present for each communication system, it was found that VDES provides a delay in the order of seconds, whilst 4G and 5G would transmit this in a fraction of a second. Further considering that many of these requests will be sent prior to departure, Wi-Fi could potentially also be used while a ship is in port.

Preferred Technology (ies): VDES (away from coast), Wi-Fi (in port) 4G/5G (in port/near the coast)

4.1.7 Search Plan

Transmission of a number of waypoints to provide information on a search plan is considered to be a low data application. NAVDAT is recommended to support this application as it supports multicast, can easily support the expected data demands, provides good coverage and is dedicated for maritime use.

Although it is acknowledged that one way NAVDAT broadcasts may be used for sending search plan information, an additional mechanism may be needed for an aircraft or vessel involved in search and rescue to report back to a controller or lead. A combination of NAVDAT and VDES may therefore be considered.

Preferred Technology (ies): NAVDAT, VDES

4.1.8 Passenger Internet Access

Passenger Internet Access is not critical to the transit of the vessel, however it is important when considering the use of the candidate technologies and the potential impact of peak use on other systems that do support safety of navigation.

The 4G and 5G network provide good capacity for passenger internet access, but there would be potential delays using Inmarsat GX system at peak times. The advantage of the Inmarsat GX service is that the coverage is far greater than that of 4G and 5G networks. However, the number of other types of users for the GX service may mean the effective data rate available to passengers could be reduced further. Whilst in port, passengers could use a port-side Wi-Fi network (802.11ac standard). The peak rates could be achieved by a wired access point serving a hotspot. Wi-Fi hotspots on board ships utilise the Inmarsat GX service to receive their broadband service and would therefore provide the same data rates as those enabled by the GX service.

Preferred Technology (ies): 4G/5G close to port, Inmarsat GX (away from port, but achieved peak data rates likely to be lower than advertised maximum due to cross industry sharing of service)

4.2 Response

To verify the suitability of candidate technologies to address the requirements for digital communications in the maritime environment the following will be addressed:

- 3.1 Confirming range of candidate technologies
- 3.2 Matching candidate technologies to requirements

5 Strategic Challenge 4 – Infrastructure

The candidate systems identify the technology options for use when transferring data. The next step is to determine requirements for infrastructure to support the technologies and how the data can be transferred. There is a requirement for both shore and ship-based capabilities, which are being addressed in different manners. For IALA members, guidance will be required on prioritising actions to ensure technology(ies) are in place to address the requirements.

Existing guidance is provided on the Common Shore-Based System Architecture, looking to provide an infrastructure approach 'fit for e-Navigation'. The maritime cloud is being developed as a means to link ship and shore within an 'internet of things' approach.

To ensure the benefit of digital communications is realised there is a need to address both the shore (and satellite) side as well as the equipment on-board vessels, with standards developed and implemented to support a communications approach that is seamless to the user.

5.1 Common Shore-Based System Architecture

The Common Shore-Based System Architecture (CSSA) describes the technical set-up of the shore-based system and have been developed for IALA members. The core of the CSSA is the technical service, which will encapsulate functions to address a specific technology or user, depending on the service to be provided.

The CSSA is a system engineering model, with a modular concept and scalable design. As such, it is a ‘future proof’ concept which can support developments in the Maritime Cloud or other similar approaches, making use of multiple digital communication technologies.

The CSSA technical services include:

- Data Collection and Data Transfer Services (DCT) – interfacing shore-based systems; information could include vessel position information (AIS, Radar); aids to navigation information; environmental sensor information.
- Value Added Data Processing Services (VAD) – opportunity to link additional data to the raw data from the DCT.
- User Interaction Service (UIA) – providing the Human-Machine Interface (HMI) link.
- Gateway service (GWY) – where the interface with technologies for data exchange – shore-shore; shore-ship; and reception of information ship-shore. The GWY is designed to interact with multiple technologies.

IALA has provided guidance on an appropriate shore-based system infrastructure – IALA Recommendation E-NAV 140 and IALA Guideline 1114. While an overview of the Common Shore-Based System Architecture is provided here, it is recommended to consult the base documents for further details.

5.2 Maritime Cloud

Under the EU led project Efficiensea and EfficienSea 2.0 the concept of a maritime ‘internet of things’ approach, called the Maritime Cloud, has evolved.

The Maritime Cloud concept has been derived as “A communication framework enabling efficient, secure, reliable and seamless electronic information exchange among all authorized maritime stakeholders across available communication systems”, based on the IMO e-navigation strategy. The vision reaches beyond the IMO strategy, matching the goals of the EU e-maritime initiative and more.

The mission of the Maritime Cloud is to enable an open and vendor-neutral platform for the maritime sector that facilitates information exchange easily and securely across candidate digital communications technologies such as the 4G / 5G, VDES, satellite or digital radio links.

It is intended to allow for the interconnecting of software systems on board various ship types, on offshore structures or on shore, including dedicated type-approved systems (e.g., ECDIS) and more ubiquitous personal devices, like smartphones, tablets and personal computers, according to standardized interfaces, protocols and access control rights.

The Maritime Cloud can be regarded much like the Internet as the enabler of interoperable systems to meet the various user requirements.

Information on the Maritime Cloud is available from the website – www.maritimecloud.net .

5.3 Response

Looking at the candidate technologies, based on the service requirements, it becomes possible to prioritise efforts when adapting and adopting enhanced digital data communications.

What technologies are currently in place and how effective are they?

- For example: VHF voice for VTS; NAVTEX; etc.

What infrastructure is currently in place / life-cycle maintenance status / possible to update?

- For example: existing NAVTEX infrastructure could be updated to NAVDAT; existing AIS shore station infrastructure could be updated to VDES shore station; etc.

To address the challenge of infrastructure – both in terms of physical equipment as well as digital data exchange capabilities (for example, through the maritime cloud or the internet) the following will be addressed:

- 4.1 Inventory of current / existing infrastructure and life-cycle maintenance cycles
- 4.2 Effectiveness of current / existing infrastructure
- 4.3 Identification of requirements for infrastructure to support new / developing technologies
- 4.4 Prioritising update / implementation of infrastructure.

6 Implementing digital data communications strategy

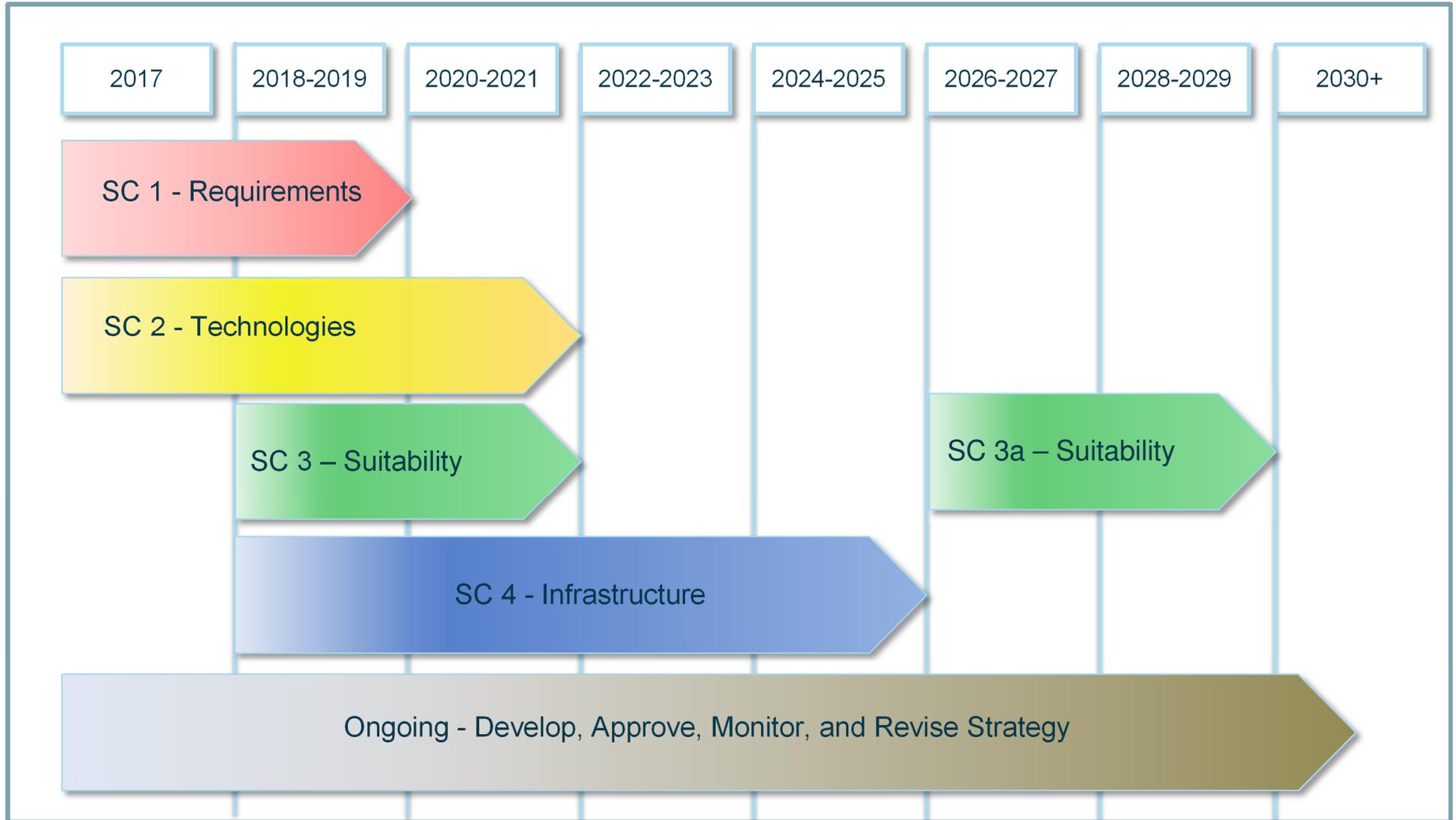
This strategy has been developed for a phased implementation process, noting the requirement to address ongoing technological developments in light of specific requirements.

The four strategic challenges, with corresponding response actions, will require a coordinated and international approach. The time-line for addressing the elements in this strategy is presented in

Figure 2.



Figure 2 – Implementation of the Strategy for Digital Communications in the Maritime Environment



Annex A – Definitions and Acronyms

ACCSEAS	Accessibility for Shipping, Efficiency, Advantages and Sustainability
AIS	Automatic Identification System
AIS 1	AIS Default Channel 1 - 161.975 MHz (Ch. 87B//2087)
AIS 2	AIS Default Channel 2 - 162.025 MHz (Ch. 88B/2088)
ASM	Application Specific Messages
AtoN	Aid to Navigation
bps	bits per second
CCTV	Closed-Circuit Television
Circ.	Circular (IMO document)
COMSAR	Sub-Committee on Communications and Search and Rescue (IMO)
DMR	Digital Mobile Radio
DSC	Digital Selective Calling
ECDIS	Electronic Chart display & Information System
ENC	Electronic Navigation Chart
ETA	Estimated Time of Arrival
FAL	Facilitation Committee (IMO)
FEC	Forward error correction
Gbps	Gigabits per second, 10^9 bits per second
GHz	Gigahertz, 10^9 Hz
GIS	Geographic Information System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
HF	High Frequency
IAMSAR	International Aeronautical and Maritime Search and Rescue (manual)
IALA	International Association of Marine Aids to navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IHO	International Hydrographic Organization
Inmarsat GX	Inmarsat Global Express
IMO	International Maritime Organization (UN)
IMT	International Mobile Telecommunications
IP	Internet Protocol
IS	Information Service
ISPS	International Ship and Port Facility Security Code
ITU	International Telecommunications Union
ITU-R	International Telecommunication Union-Radiocommunication Sector



kb	kilobits
kB	kilobytes (= 8 kilobits)
kpbs	kilobits per second, 10^3 bits per second
kHz	kilohertz, 10^3 bits per second
LF	Low Frequency
LTE	Long Term Evolution
LPS	Local Port Service
MARPOL	International Convention for the prevention of pollution from ships (1973) (as amended)
MAS	Maritime Assistance Service
Mbps	Megabits per second, 10^6 bits per second
MEDEVAC	Medical evacuation
METAREA	Geographical sea regions for the purpose of co-ordinating the transmission of meteorological information
MF	Medium Frequency
MHz	megahertz
MMSI	Maritime Mobile Service Identity
MSC	Maritime Safety Committee (IMO)
MSI	Maritime Safety Information
MSP	Maritime Service Portfolio(s)
MSS	Mobile Satellite System
MSW	Maritime Single Window
NAS	Navigation Assistance Service
NAVAREA	Geographic areas in which various governments are responsible for navigation and weather warnings
NAVTEX	Navigational Telex (service
NCSR	National Centre for Sensor Research
NM	Nautical Mile
OSC	On-scene commander
RCC	Rescue Co-ordination Centre
RTCM	Radio Technical Commission for Maritime Service
SAR	Search and Rescue
SART	Search and Rescue Transponder
SAT	Satellite
SIP	Strategic Implementation Plan
SOLAS	International Convention for the Safety of Life at Sea, (IMO)
SRU	Search and Rescue Unit
Tbps	Terabits per second, 10^{12} bits per second

TDMA Time-division multiple access
TMAS Telemedical Maritime Assistance Service
TOS Traffic Organization Service
UTC Co-ordinated Universal Time
VDE VHF Data Exchange
VDES VHF Data Exchange System
VDL VHF Data Link
VHF Very High Frequency (30 MHz to 300 MHz)
VOS Voluntary observing ship
VTS Vessel Traffic Information Service
WLAN Wide Local Area Network
WRC World Radiocommunications Conference
WWRNS World-wide Radionavigation System



Annex B - References

1. International Maritime Organisation, “Report to the Maritime Safety Committee: Annex 7 Draft e-Navigation Strategy Implementation Plan,” 2014.
2. International Maritime Organisation, SN Circ. 290, “Guidance on the use of AIS application-specific messages”, London, 2010.
3. International Telecommunications Union, *Recommendation ITU-R M.1371-5*, 2014.
4. International Telecommunications Union, *Recommendation ITU-R M.493-12*, 2017
5. International Telecommunications Union, *Recommendation ITU-R M.1084-4*
6. General Lighthouse Authorities, Research and Radionavigation Directorate “eNavigation Communication Requirements Study” 2015



Annex C – Application data size conversions

Application	Max single message size (bits)		Max single message size (Bytes)	
	Vessel tx	Shore tx	Vessel tx	Shore tx
1 Byte = 8 bits				
No-Go area	400	20,000,000	50	2,500,000
Route Exchange	880		110	
Maritime Safety Information	320	2,400	40	300
Weather Data	20,800	276,480	2,600	34,560
Telemedicine	1,000,000 per second (video link) 1,760,000 (total, biomedical records)	1,000,000 per second (video link)	125,000 per second (video link) 220,000 (total biomedical records)	125,000
Maritime Single Window	240,000		30,000	
Vessel Operation Coordination Tool		1,100		138
Passenger Internet Access	12,000 (per second)	800,000 (per second)	1,500 (per second)	100,000 (per second)

Annex D - Supporting communication systems inclusion justifications

System	Justification for inclusion
NAVDAT	development on NAVTEX with high data rates, suggested by GLA R&RNAV
VDES	extension of AIS to include more channels - seems the immediate answer to overcrowded AIS/VHF channels, and suggested by GLA R&RNAV
Digital VHF HF	Digital data communication using digital VHF
4G	included in previous report
5G	Future system to be aware of - higher data rates and expected delivery by 2020
WiFi	suggested by GLA R&RNAV
Inmarsat C	Satellite comms system, providing a store and forward service
Inmarsat GX	Overseen by IMSO and safety critical considering the support of GMDSS



Annex E - VDES channel applications

VHF Data Communications (including ASM and VDE)			AIS	
Sub-group	Data communications for ASM	Data communications for VDE	AIS for safety of navigation	AIS long range
Radio channels	Channels 27 and 28 World-wide dedicated channels	Channels 24, 84, 25, 85, 26, 86 for VDE terrestrial and satellite	AIS-1 & AIS-2 (simplex)	Channels 75 and 76 (simplex)
Functionality	Marine safety information Marine security information Short safety related messages General purpose information communication	General purpose data exchange Robust high speed data exchange VDE satellite communications	Safety of navigation Maritime locating devices	Satellite detection of AIS Locating during SAR
Message types for AIS protocol	IMO SN.1/ Circ.289 international application specific messages Regional application specific messages Base Station		Vessel identification Vessel dynamic data Vessel static data Voyage related data Aids to Navigation Base Station	Satellite detection of AIS Message 27
Applications	Area warnings and advice Meteorological and hydrographic data Traffic management Ship-shore data exchange Channel management	High message payload Satellite communications	Ship to ship collision avoidance VTS Tracking of ships Locating in SAR VDL control (by Base Station)	Detection of vessels by coastal states beyond range of coastal AIS base stations

Annex F - Communication system capacity results

F.1 Time to service theoretical peak demand

This table provides the time taken to transmit the peak loads (kb) for each application.

Application	Time to service theoretical peak demand (seconds)																	
	NAVDAT		VDES VDE		VDES ASM		Digital VHF HF		Wi-Fi		4G		5G		Inmarsat C		Inmarsat GX	
	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx	vessel tx	shore tx
No Go		9.11 E+05	5.69 E-02	2.85 E+03	1.82 E+00	9.10 E+04	3.64 E+00	1.82 E+05	1.17 E-10	5.83 E-06	3.24 E-05	1.62 E+00	1.62 E-06	8.09 E-02	5.18 E+03	2.59 E+08	6.21 E-02	3.11 E+03
Route Exchange			1.56 E-02		4.99 E-01		9.99 E-01		3.20 E-11		8.88 E-06		4.44 E-07		1.42 E+03		1.70 E-02	
MSI		1.32 E+02	5.49 E-02	4.12 E-01	1.75 E+00	1.32 E+01	3.51 E+00	2.63 E+01	1.12 E-10	8.44 E-10	3.12 E-05	2.34 E-04	1.56 E-06	1.17 E-05	4.99 E+03	3.74 E+04	5.99 E-02	4.49 E-01
Weather Data		1.52 E+04	3.57 E+00	4.74 E+01	1.14 E+02	1.52 E+03	2.28 E+02	3.03 E+03	7.31 E-09	9.72 E-08	2.03 E-03	2.70 E-02	1.01 E-04	1.35 E-03	3.24 E+05	4.31 E+06	3.89 E+00	5.18 E+01
Telemedicine		4.55 E+04	3.92 E+02	1.42 E+02	1.25 E+04	4.54 E+03	2.51 E+04	9.08 E+03	8.03 E-07	2.91 E-07	2.23 E-01	8.07 E-02	1.11 E-02	4.03 E-03	3.56 E+07	1.29 E+07	4.28 E+02	1.55 E+02
MSW			3.41 E+01		1.09 E+03		2.18 E+03		6.98 E-08		1.94 E-02		9.68 E-04		3.10 E+06		3.72 E+01	
VOCT		8.60 E+01		2.68 E-01		8.58 E+00		1.72 E+01		5.50 E-10		1.53 E-04		7.63 E-06		2.44 E+04		2.93 E-01
Passenger Internet Access		1.45 E+04	6.81 E-01	4.54 E+01	2.18 E+01	1.45 E+03	4.36 E+01	2.90 E+03	1.40 E-09	9.31 E-08	3.87 E-04	2.58 E-02	1.94 E-05	1.29 E-03	6.20 E+04	4.13 E+06	7.43 E-01	4.96 E+01

F.2 Average load ratio

The following table provides the ratio of average load (kbps) of the e-Navigation applications to the effective maximum data rates provided by the communication systems

Application	Time delay to transmit peak amount of data (seconds)																	
	NAVDAT		VDES VDE		VDES ASM		Digital VHF HF		Wi-Fi		4G		5G		Inmarsat C		Inmarsat GX	
	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in
No Go		6.33 E+01	3.95 E-06	1.98 E-01	1.26 E-04	6.32 E+00	2.53 E-04	1.26 E+01	8.10 E-15	4.05 E-10	2.25 E-09	1.12 E-04	1.12 E-10	5.62 E-06	3.60 E-01	1.80 E+04	4.31 E-06	2.16 E-01
Route Exchange			4.34 E-05		1.39 E-03		2.77 E-03		8.89 E-14		2.47 E-08		1.23 E-09		3.95 E+00		4.73 E-05	
MSI		4.94 E-02	6.86 E-05	1.54 E-04	2.19 E-03	4.94 E-03	4.39 E-03	9.87 E-03	1.41 E-13	3.16 E-13	3.90 E-08	8.77 E-08	1.95 E-09	4.39 E-09	6.24 E+00	1.40 E+01	7.49 E-05	1.68 E-04
Weather Data		1.76 E+00	4.13 E-04	5.49 E-03	1.32 E-02	1.75 E-01	2.64 E-02	3.51 E-01	8.46 E-13	1.12 E-11	2.35 E-07	3.12 E-06	1.17 E-08	1.56 E-07	3.76 E+01	4.99 E+02	4.51 E-04	5.99 E-03
Telemedicine		1.89 E+03	1.42 E+02	5.91 E+00	4.54 E+03	1.89 E+02	9.08 E+03	3.78 E+02	2.91 E-07	1.21 E-08	8.07 E-02	3.36 E-03	4.03 E-03	1.68 E-04	1.29 E+07	5.38 E+05	1.55 E+02	6.46 E+00
MSW			3.94 E-04		1.26 E-02		2.52 E-02		8.08 E-13		2.24 E-07		1.12 E-08		3.59 E+01		4.30 E-04	
VOCT		9.95 E-04		3.11 E-06		9.93 E-05		1.99 E-04		6.37 E-15		1.77 E-09		8.83 E-11		2.83 E-01		3.39 E-06
Passenger Internet Access		1.45 E+04	6.81 E-01	4.54 E+01	2.18 E+01	1.45 E+03	4.36 E+01	2.90 E+03	1.40 E-09	9.31 E-08	3.87 E-04	2.58 E-02	1.94 E-05	1.29 E-03	6.20 E+04	4.13 E+06	7.43 E-01	4.96 E+01

