MARINTEK REPORT

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The role of digital communication technology in e-Navigation (Draft 0.5)

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ABSTRACT

This paper discusses the new and highly relevant issue of e-Navigation that has been on the agenda for IMO[1], IALA[2] and other organisations the last few years. In particular, it will go into some depth on the need of ship to shore digital communication technology to realise the concept of e-Navigation. The paper will also analyse the communication requirements as well as the available and near future technology. Finally the paper concludes with some overall requirements for communication facilities and suggests some possible solutions that satisfy the requirements. A summary and conclusions is given in the executive summary at page 4.

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EFFORTS

6th Framework Programme

Flagship

MarCom broadband at sea

[1] IMO – International Maritime Organization
[2] IALA – International Association of Marine Aids to Navigation and Lighthouse Authorities

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GROUP 2	Communication technology	Kommunikasjonsteknologi
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- Flagship (EU project number TIP5-CT-2006-031406), sub-project D1 and C1. D1 has provided investigations on communication technology for ship to shore communication via satellite as well as general operational requirements. C1 has provided information on emergency management.
- Efforts (EU Project number FP6-031486), work package WP3.1. The work package has provided information on general shore requirements and in particular port approach information. The WP has also provided the background information on e-Navigation and the implications for port communication needs.
- MarCom (NRC Project number 182678/I40). MarCom has provided additional background on communication requirements as well as technology. Radio communication background has in particular been covered by MarCom.

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Executive summary and conclusions

This report goes through a range of e-navigation services that require ship to shore communication, groups them into seven categories and estimates the communication requirements for each service (Chapter 3 – summary in section 3.1). The general conclusions that can be drawn from this are:

1. Many services, including AIS, are and will most likely continue to be implemented over dedicated carriers.
2. AIS capacity is fairly close to maximum utilization and should be reserved for real-time navigation data. There are limited possibilities to add more data to this carrier.
3. Capacity demands are 20 times higher near coast than at open sea and double in port compared to near coast. Thus, a shore based communication infrastructure can be used to cover coast and port approaches and by that complement satellite systems.
4. A bandwidth of around 200 kbps should be sufficient to cover all relevant e-Navigation services that are not going to be implemented on a satellite service in any case. If VTS image transfer is kept out, it should be sufficient with 100 kbps even when some crew infotainment services are included.

The report also looks at some factors that can determine what kind of communication system is most appropriate for future e-Navigation services (Chapter 4). The conclusion is that a mixed communication solution may be needed:

1. A GEO (or LEO) system for high seas and for covering various commercial services that require very high bandwidths.
2. A satellite system that covers Polar Regions beyond what GEO satellites reach. However, as communication demands are relatively low in these areas, one may perhaps be able to make do with a dedicated HF solution.
3. A system to cover coastal areas and port approaches. A terrestrial system could satisfy the corresponding requirements and may be the most optimal solution.

Section 5.4 indicates that a terrestrial system may have certain benefits compared to satellite. If a terrestrial system is to be used, there are three technical solutions that warrant special attention:

1. Digital VHF seems to have enough bandwidth, it has very good range and it uses frequencies that are already allocated to maritime mobile services.
2. WiMax on 790 MHz is attractive as it gives very good bandwidth and reasonable range, it uses a frequency that is available in most of the world and off the shelf hardware should be available for equipment and systems soon.
3. WiMax in general is an interesting solution, but it will be a challenge to allocate enough bandwidth in ports and coastal areas for e-Navigation services.

List of abbreviations

AMVER – Automated Mutual Assistance Vessel Rescue System
bps – Bits per second
EPIRB – Emergency Position Indicating Radio Beacon
CCTV – Closed Circuit Tele Vision
CDMA – Carrier Detect Multiple Access
COMSAR – IMO MSC Communication and SAR sub-committee
COSPAS – (Russian) “Space System for the Search of Vessels in Distress”.
DSC – Digital Selective Calling
DVB-RCS – Digital Video Broadcast, Return Channel via Satellite
ECDIS – Electronic Chart Display and Information System
ENC – Electronic Navigational Chart
IALA – International Association of Aids to Navigation and Lighthouse Authorities
IMO – International Maritime Organization
GLONASS – (Russian) “Global Navigation Satellite System”
GMDSS – Global Maritime Distress Safety System
GNSS – Global Navigation Satellite System
GPS – Global Positioning System
HF – High Frequency (3MHz to 30 MHz)
kbps – Kilobits per second
kByte – Kilo byte (1024 byte)
LRIT – Long Range Identification and Tracking
MAN – Metropolitan Area Network
Mbyte – Mega byte (1 024 kByte)
MF – Medium Frequency (300 kHz to 3 MHz)
MIO – Maritime Information Object
MSC – IMO Maritime Safety Committee
NAV – MSC Navigation subcommittee
PPU – Portable Pilot Unit
SAR – Search and Rescue
SARSAT – SAR Satellite Aided Tracking
SOLAS – Convention of Safety of Life at Sea
SSAS- Ship Security Alert System
VHF – Very High Frequency (30 – 300 MHz)
VSAT – Very Small Aperture Terminal (Satellite communication)
VTS – Vessel Traffic Services
UHF – Ultra High Frequency (300 MHz – 3 GHz)

1. Introduction

1.1 Scope

This report discusses e-Navigation and its requirements to digital communication bandwidth. E-Navigation may be a critical development to ensure safe, secure and efficient maritime transport, also in an increasingly more demanding future. However, the realization of e-Navigation will require increased digital exchange of information between ship and shore and this report will examine this challenge in some detail.

The report will also contain a quantitative and qualitative analysis of possible communication requirements as well as an analysis of possible carriers for the communication and benefits and drawbacks of these.

1.2 Structure of document

This chapter of the document contains general information about the document, including the revision history.

Chapter two gives background information for the concept of e-Navigation. This is information intended for those that are not familiar with the concept and its development.

Chapter three gives a description of existing and emerging maritime communication services and requirements. Annex 1 gives a detailed description of how these requirements have been quantified and an overall summary is provided in section 3.1.

Chapter four gives an overview of the most relevant types of communication technology that is or will become available in the foreseeable future. This has focus on terrestrial infrastructures.

Chapter five discusses the benefits and drawbacks of terrestrial and satellite systems and the possible approaches to create an e-navigation solution that works internationally. This also includes our points of view on these issues and can be read as the authors' conclusion on this analysis.

1.3 Revision history

V0.1 – 2008-03-07 – øjr: First draft
V0.2 – 2008-04-07 – øjr: Fairly complete on e-Navigation
V0.3 – 2008-04-21 – øjr: Fairly complete on required services
V0.4 – 2008-05-20 – bk/øjr: Final structure, draft content
V0.5 – 2008-05-26 – bk/øjr: Final draft

2. Background

2.1 A short history of e-Navigation and the current definition

e-Navigation as an official issue in the IMO originated in a proposal to the MSC[1], session 81, in December 2005 to develop this particular concept into an international "standard" [MSC 81/23/10]. However, the term e-Navigation occurred some time before that, see e.g., [Wadsworth 2005]. In the latter paper e-Navigation is used as an abbreviation for "Electronic Navigation" while others used the term "Enhanced Navigation". It is now generally accepted that "e-Navigation" should be thought of as a brand without any special meaning attributed to the "e".

MSC 81 decided that e-Navigation should be included in work programme for the NAV[2] and the COMSAR[3] sub-committees. A report from the work is expected for the 85th session of MSC, late in 2008. This issue were then discussed the 52nd session of NAV in July 2006 and the outcome was the establishment of a correspondence group that was tasked with bringing this matter up to the 11th session of COMSAR and to provide a preliminary paper on e-Navigation to NAV 53 in 2007. COMSAR 11 in February 2007 provided additional information to the NAV correspondence group, but left the work of drafting a strategy to the NAV group.

In September 2006, IALA started the work in its e-Navigation from the two existing AIS and Radionavigation committees. This work was coordinated with the NAV correspondence group, but giving its focus on aids to navigation, IALA made their own temporary definition of e-Navigation:

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

In addition to this, the IALA working group also pointed out that three prerequisites needed to be realized:

- world wide coverage of navigational areas by Electronic Navigation Charts (ENC),
- a robust fail-safe electronic positioning system (with redundancy), and
- an agreed communication infrastructure to link ship and shore.

At NAV 53 the issue of e-Navigation was revisited and IALA provided its points of view [NAV 53/13/3]. NAV agreed to provisionally adopt the IALA definition and, further, more tentatively defined that the core objectives of an e-navigation concept using electronic data capture, communication, processing and presentation should [NAV 53/13/22] -

1. facilitate safe and secure navigation of vessels having regard to hydro-graphic, meteorological and navigational information and risks;

[1] MSC – IMO's Maritime Safety Committee
[2] NAV – IMO MSC sub-committee on Navigational safety
[3] COMSAR – IMO MSC sub-committee on Communication, Search and Rescue

2. facilitate vessel traffic observation and management from shore/coastal facilities, where appropriate;
3. facilitate communications, including data exchange, among ship to ship, ship to shore, shore to ship, shore to shore and other users;
4. provide opportunities for improving the efficiency of transport and logistics;
5. support the effective operation of contingency response, and search and rescue services;
6. demonstrate defined levels of accuracy, integrity and continuity appropriate to safety-critical system;
7. integrate and present information onboard and ashore through a human interface which maximizes navigational safety benefits and minimizes any risks of confusion or misinterpretation on the part of the user;
8. integrate and present information onboard and ashore to manage the workload of the users, while also motivating and engaging the user and supporting decision-making;
9. incorporate training and familiarization requirements for the users throughout the development and implementation process;
10. facilitate global coverage, consistent standards and arrangements, and mutual compatibility and interoperability of equipment, systems, symbology and operational procedures, so as to avoid potential conflicts between users; and
11. be scalable, to facilitate use by all potential maritime users.

The correspondence group will continue the work on the definition until NAV 54 in the summer of 2008 and thereafter to MSC 85 in the fall of 2008.

2.2 e-Navigation and ship-shore communication

IALA has presented the following figure as an illustration of what e-Navigation can consist of [NNC07].

This is a fairly comprehensive overview of the possibilities and challenges inherent in the concept of e-Navigation. Without going into details on the different input, outputs and benefits, it illustrates that an important underlying principle of e-Navigation is *integration*:

- Integration between systems and information on board;
- Integration between services, systems and information on shore;
- Integration between ship and shore systems; and
- Integration between different ships' systems.

In addition, this integration must obviously be followed up by standardization, training and, in general, taking the human element into account [MSC 1091]. To realize this vision, IALA has already pointed out the three major challenges listed in the previous section: ENCs, electronic positioning systems and communication.

Without trying to rate the complexity or importance of these challenges, one can observe that the third – communication – requires immediate attention as there is a very high pressure on allocation of radio frequencies today. Later in this paper, we will argue that new maritime communication mechanisms need to be developed to realize e-Navigation and that this may also require new internationally standardized frequencies.

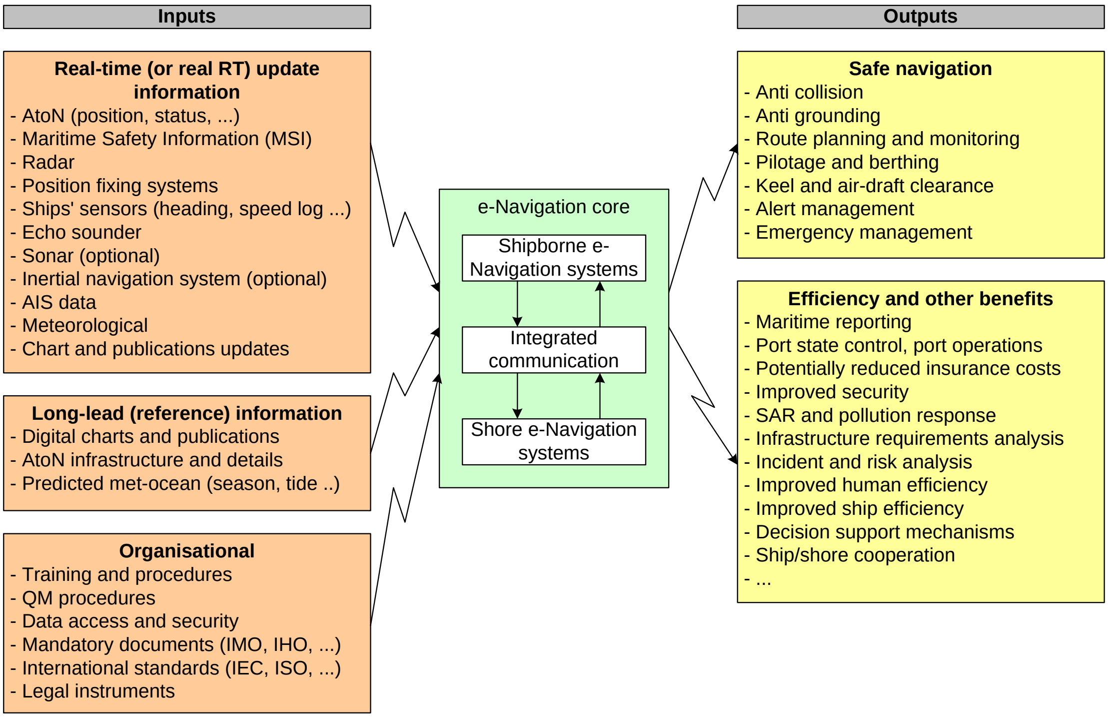


Figure 1 – e-Navigation overview

It is interesting to note that maritime applications have a significant share of frequencies in the bands up to and including VHF (around 300 MHz), but almost no dedicated frequencies above that, the exceptions being mainly hand held UHF, emergency beacons and radar frequencies [ERC 2002]. This seems to reflect the development from the first Radiotelegraph Conference in Berlin in 1906 where the first international “Table of Frequency Allocations” almost exclusively addressed maritime applications to the situation today where mobile communication is an everyday fact of life.

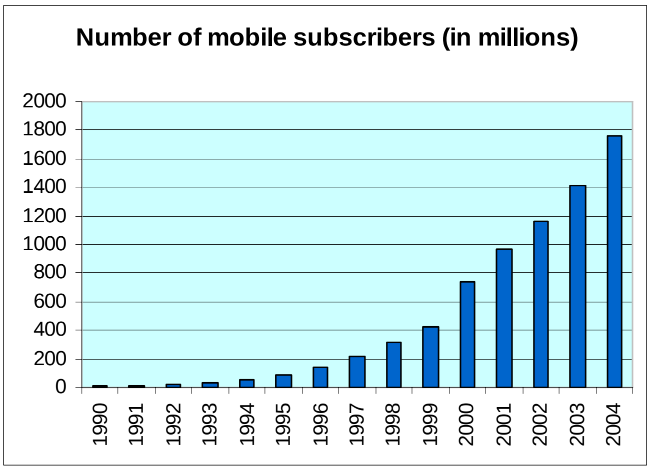


Figure 2 – Increase in number of mobile radio subscribers

Figure 2 illustrates this process by showing the near explosive growth in use of mobile radio communication facilities in the world since 1990 [ITU 2006]. As mobility also is becoming more and more international, this puts a tremendous pressure on the allocation of frequencies for standardised international communication, which is necessary for the realization of the e-Navigation concept.

This paper will discuss this issue and requirements for wireless communication facilities to realise e-Navigation and also e-Maritime.

2.3 e-Navigation, e-Maritime and e-Freight: Communication types

It is quite obvious that e-Navigation can be of great benefit also to commercial shipping and maritime goods transport. Increases in safety, security and, hence, reliability will have direct economical and operational benefits. Also, better access to information about where the ship is and what it is doing can obviously be used in operational setting. Finally, as was pointed out above, wireless communication facilities will be important for the realization of e-Navigation and better communication mechanisms will also be a critical factor in improving the commercial operation of the ship.

E-Navigation is focused on safety and security and does not directly address the commercial side of operations. Also, goods transport will normally involve more actors than just the ship and the port and will to a certain degree fall outside the scope of e-Navigation. To look at the issues beyond e-Navigation, the terms “e-Maritime” and “e-Freight” has been suggested to cover this broader perspective [Pipitsoulis 2007]. E-Navigation will most likely be a subset of e-Maritime.

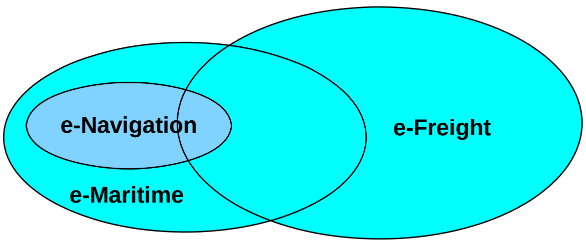


Figure 3 – e-Relationships

With focus on radio communication, it is important to take this broader view and also to acknowledge the different nature of the communication types. In this paper we will propose the seven groups of communication illustrated in **Figure 4**.

Figure 4 – Communication types

The next section will give a more detailed definition of these types, but as an overview one can use the following brief explanations:

- *Emergency management:* Communication related to accidents at sea, either for assistance to other ships or to get aid to oneself.

- *Position and safety reporting:* AIS and LRIT ship position reports, GMDSS emergency alarms as well as ship security alarm systems. AMVER reports can also be included here.
- *Additional navigational information:* Information to the ship about local navigational issues. Can include differential GPS correction, NAVTEX and some AIS messages.
- *Mandatory ship reporting:* Reporting to VTS and other ship reporting areas as well as mandatory reporting to port state authorities in conjunction with port calls.
- *Operational reporting:* Daily noon reports, machinery reports, arrival and departure reports exchanged with owner and owner's associates.
- *Cargo and passengers:* In passenger ships, one will see that the passengers in many cases pay for advanced communication facilities through their private use. This may also be the case for certain cargos, where cargo owner will pay for cargo supervision.
- *Crew infotainment:* Crew's private communication.

There is obviously some overlap between these communication types as has been indicated in the figure. Note also that almost all of this communication may be either spoken (including voice channel facsimile) or digital. It is only some parts of the safety and security communication that must be digital. However, in the scope of e-Navigation we will assume that the information is exchanged digitally. To achieve integration, as one of the main principles of e-Navigation, it is necessary to be able to exchange information between computers automatically.

3. Communication requirements by groups

This chapter divides communication requirements into a number of groups. The grouping is based on the one used in **Figure 4**. It is to some degree an arbitrary division and this is indicated by the overlap between groups in the figure. However, the grouping has been done to keep related and similar services together and to facilitate a certain structure to the analysis.

Each communication group is summarised in a table as shown, e.g., in **Table 5**. The columns in the table are:

- *Service:* Name and description of service in question.
- *bps:* Bits per second, capacity of normal carrier on which service is implemented.
- *Bytes:* Number of bytes in a typical message.
- *Tot BW OS:* Total percentage of bandwidth (as given by bps) used in an Open Sea scenario.
- *Tot BW Co:* Total percentage of bandwidth (as given by bps) used in a Costal scenario.
- *Tot BW PA:* Total percentage of bandwidth (as given by bps) used in a Port Approach scenario.
- *PU/CO/SP:* Public service, commercial service or special purpose service. The latter means a service that in any case requires specialized communication systems due to heavy throughput demands or special safety or response requirements.

- *Dedic.*: Dedicated carrier, e.g., as for AIS, and thus of less interest in the scope of this report.

Annex A gives more details of how the data has been produced. In particular, it explains how any differences between the scenarios have occurred. One should also note that these figures are not very accurate and only indicates the order of magnitude of traffic.

The chapter will also look at the communication requirements from two perspectives: What is common best practice today and what one can expect from a more demanding e-Navigation scenario. The latter identifies services that are known today and to some degree tested, but are not yet in common use. One can also probably envisage even more esoteric, but still useful services that will arise if and when sufficient bandwidth is available. This is not covered in this report.

3.1 Summary of communication requirements

With regards to communication carrier, the services described below can be divided into four main groups and these will be discussed in the following.

3.1.1 Dedicated narrow band services

These are services operating over a dedicated carrier and which use little band width.

Table 1 – Dedicated narrow band services

Service	Bytes OS	Bytes Co	Bytes PA
DSC (via MF, HF or Inmarsat)	0,0000037	0,0000037	0,0000037
EPIRB (406 MHz COSPAS SARSAT)	0,0000009	0,0000009	0,0000009
SSAS (Inmarsat)	0,0000009	0,0000009	0,0000009
GNSS (GPS, Glonass, Galileo)	4,0000	4,0000	4,0000
LRIT position report (Inmarsat)	0,0004	0,0004	0,0004
DSC (via MF, HF or Inmarsat)	0,0178	0,0533	0,0889
AMVER (position report)	0,0004	0,0004	0,0004
Differential GNSS (RTCM)	0,60	0,60	0,60
NAVTEX (MSI)	0,21	0,21	0,21
SafetyNET (MSI over Inmarsat)	0,21	0,21	0,21
Weather fax	19,68	19,68	19,68
Sum	**25**	**25**	**25**

The table summarises the transmissions per day from each ship to give an impression of the actual bandwidth required. As can be seen, even with a high number of ships, this is not a large amount.

One can expect these services to be kept and probably expanded in an e-Navigation system. However, bandwidth will still be fairly low and carriers will still be dedicated. Thus, these services will not have a significant influence on selection of carrier for future e-Navigation services.

3.1.2 AIS based transmissions

AIS carries ship status, AtoN information and some other mostly navigation related data today. Although the information also can be utilized for other purposes, e.g., logistics and security, the service remains navigational in its nature.

Table 2 – AIS based services

Service	Tot BW OS	Tot BW Co	Tot BW PA
AIS position report (msg. 1, 2, 3)	1 %	22 %	56 %
AIS (other messages, AtoN)		7 %	7 %
Sum	**1 %**	**29 %**	**63 %**

If the usage examples are summed up one sees that the bandwidth is utilized quite heavily. One cannot assume that there is much spare capacity for future e-Navigation services on this carrier, unless the number of channels is increased or the modulation technique is changed.

Spare bandwidth is available in sparsely populated areas, but any use of this carries in these areas would not be possible to standardize for general purpose international traffic.

3.1.3 Operational public and commercial service information

The third group is services that are related to ship operation. This is tabulated below where all bit rates have been normalized to 100 kbps and capacity demands adjusted correspondingly.

Table 3 – Operational services

Service	bps	Tot BW OS	Tot BW Co	Tot BW PA	Type
Ship reporting	100000		0,02 %	0,05 %	PU
Coast state notification	100000		0,04 %		PU
Port arrival notification	100000		0,93 %	0,46 %	PU
Voyage orders and reports	100000	0,01 %	0,06 %	0,14 %	CO
Commercial port call messages	100000		0,15 %	0,37 %	CO
Operational reports	100000	0,02 %	0,17 %	0,42 %	CO
Weather forecast	100000	0,00 %	0,05 %	0,12 %	CO
Crew communication to family/home	100000	1,85 %	18,52 %	46,30 %	CO
Crew training	100000	0,19 %	1,85 %	4,63 %	CO
VTS coordination	100000		0,93 %	2,31 %	PU
MIO	100000	0,11 %	0,67 %	0,67 %	PU
PPU - VTS image	100000		80,00 %	80,00 %	PU
Real time met-ocean	100000	0,22 %	0,22 %	0,22 %	PU
Ship reporting	100000		0,33 %	0,83 %	PU
Coast state notification	100000		1,11 %	2,78 %	PU
Port arrival notification	100000		1,11 %	2,78 %	PU
Commercial port services	100000		1,85 %	4,63 %	CO
Navigational data update (ENC)	100000	0,09 %	0,93 %	2,31 %	CO
Operating manuals, documents	100000	0,01 %	0,09 %	0,23 %	CO
External maintenance and service	100000	0,09 %	0,93 %	2,31 %	CO
Sum		**2,59 %**	**109,94 %**	**151,56 %**	
Sum w/o PPU and Crew infotainment		**0,55 %**	**9,56 %**	**20,63 %**	

These are services that could be suitable for a dedicated e-Navigation data carrier. To better show this note the crew infotainment has been changed to “CO” from “SP” to cater for demands on a shared data carrier. As can be seen, a 100 kbps data carrier is sufficient with the exception of carriage of VTS images to PPU. Even these data could easily be accommodated with an increase of the bandwidth to above 200 kbps.

Note also that if one removed crew infotainment and PPU data from the requirements we end up with a sufficient bandwidth of about 25 kbps, even in congested areas.

3.1.4 Remaining satellite based services

The rest of the described services are special in that they are purely commercial and require relatively high bandwidth. Note that the figures in the below table is per ship as it is assumed that a dedicated satellite link will be used to implement these.

Table 4 – Special commercial services

Service	bps	Tot BW OS	Tot BW Co	Tot BW PA	Type
Cargo telemetry, online monitoring	100000	0,02 %	0,02 %	0,02 %	SP
Special ship, data gathering	100000	800,00 %	800,00 %	800,00 %	SP
Passenger infotainment	100000	813,33 %	813,33 %	813,33 %	SP
Payments and inventory	100000	16,00 %	16,00 %	16,00 %	SP
Communication to other ship	100000	21,33 %	21,33 %	21,33 %	SP
Communication to SAR	100000	21,33 %	21,33 %	21,33 %	SP
Communication to owner's office	100000	21,33 %	21,33 %	21,33 %	SP
Crew communication to family/home	100000	37,04 %	37,04 %	37,04 %	SP
Crew training	100000	3,70 %	3,70 %	3,70 %	SP
Sum w/o special ships		**120,76 %**	**120,76 %**	**120,76 %**	

These services should be integrated in e-Navigation where appropriate, but it is clear that they will need dedicated per ship communication channels due to high bandwidth demands.

From the figures one could also estimate that future communication demands for “normal ships” might be closer to 128 kbps than 64 kbps which is fairly common today.

3.2 Today’s communication requirements

3.2.1 Emergency management

Originally and in the first version of SOLAS, emergency management was the main reason for installing radio equipment on ships. However, the actual use of the radio is obviously more dominated by normal operations. However, emergency management is still an important factor in maritime communication. The table lists the most important digital communication mechanisms currently in use. In addition, voice over satellite or VHF is obviously much more important, but is currently not in a digital format.

Table 5 – Emergency communication requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
DSC (via MF, HF or Inmarsat)	1200	32	0,00 %	0,00 %	0,00 %	SP	Y
EPIRB (406 MHz COSPAS SARS	400	8	0,00 %	0,00 %	0,00 %	SP	Y
SSAS (Inmarsat)	128	8	0,00 %	0,00 %	0,00 %	SP	N

DSC represents emergency calls over Digital Selective Calling mechanisms, mainly on VHF.

EPIRB – Emergency Position Indicator Radio Beacon can be implemented on VHF (DSC) or as part of the world wide COSPAR/SARSAT emergency beacon system. It is used only in emergencies.

SSAS – Ship Security Alert System is implemented to warn shore authorities about security problems on a ship, e.g., hijackings or terrorist attacks.

As this type of communication mainly is in use during rare emergencies, they will obviously not put a great cumulative demand on the communication carrier. However, these messages need to have very high priority.

3.2.2 Position and safety reporting

This communication group covers messages to and from the ship which are related to its navigational safety and security. For the purpose of this paper, this includes mandatory and one voluntary navigational position reports. **Table 6** shows the current required communication services for a ship in international trade.

Most of the "real time" ship reporting requirements is related to the Global Maritime Distress Safety System (GMDSS) requirements in SOLAS. In addition to the "digital" services listed below, SOLAS also requires the carriage of voice communication equipment (Satellite or normal radio). However, these are not digital in the sense that they carry computer understandable data and is left out of the table.

Table 6 – Position and safety reporting requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
GNSS (GPS, Glonass, Galileo)	50	8	64,00 %	64,00 %	64,00 %	PU	Y
AIS position report (msg. 1, 2, 3)	19200	32	1,11 %	22,22 %	56,48 %	PU	Y
LRIT position report (Inmarsat)	128	8	0,02 %	0,23 %	0,58 %	PU	N
DSC (via MF, HF or Inmarsat)	1200	32	0,12 %	3,56 %	14,81 %	PU	Y
AMVER (position report)	128	8	0,02 %	0,23 %	0,58 %	PU	N

Most of these services are operating on dedicated carriers and are of little interest as a means to increase bandwidth. However, one should note the relatively high demand on AIS that is more likely underestimated than otherwise. There is very little spare bandwidth in this channel and one cannot expect that it can be used as a major instrument to provide needed bandwidth for e-Navigation.

3.2.3 Additional navigational information

This group of communication includes data that is used by the ship and others to supply navigational information beyond purely position reports. Today this typically includes differential GPS corrections, NAVTEX and when AIS used to transmit information about aids to navigation (AtoN).

Table 7 – Additional navigational information requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Differential GNSS (RTCM)	100	36	4,80 %	4,80 %	4,80 %	CO	N
AIS (other messages, AtoN)	19200	32		6,67 %	6,67 %	PU	Y
NAVTEX (MSI)	300	128	0,57 %	0,57 %	0,57 %	PU	Y
SafetyNET (MSI over Inmarsat)	1200	128	0,14 %	0,14 %	0,14 %	PU	Y
Weather fax	2500	170000	6,30 %	6,30 %	6,30 %	PU	Y

These services provide limited load on their respective carriers. It may be worth mentioning that the AIS channel is further exploited by these services, although not with much as these estimates show.

3.2.4 Mandatory ship reporting

Mandatory ship reporting is here defined as communication between the ship and a port, port state authorities, or any other party that require information exchanges as parts of the clearing procedures for ship arrival, departure or transit. The information is traditionally sent as FAL forms[4], but relatively recently also ISPS[5] data, waste management data and any other information have been included in the information required by international or regional legislation.

This communication is often in digital form, although it can be performed via fax, e-mail or even voice in many cases. **Table 8** gives an overview of mandatory reporting requirements. The figures can be seen as typical for normal cargo ships. Container, break bulk and passenger ships will have higher requirements due to more information about the cargo the ship carries. The bit rate is typical for Inmarsat C.

Table 8 – Mandatory ship reporting requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Ship reporting	9600	1000		0,19 %	0,48 %	PU	N
Coast state notification	9600	1000		0,39 %		PU	N
Port arrival notification	9600	5000		9,65 %	4,82 %	PU	N

Ship reporting in Vessel Traffic Service zones and specially protected sea areas are normally required on entry and exit from the zone or area. Sometimes it is also required inside the zone. There are also some special requirements for reporting various observations, incidents and other abnormal situations, usually to the nearest coast state. These messages are often given via VHF radio, but can also be given via, e.g., e-mail or fax.

Coast state notifications are required for certain incidents that may endanger coastal areas. This includes accidental spills, emergencies etc. These are small messages, similar to the previous category.

Port arrival notifications are messages related to the clearance for a port call. These are message to and from port authorities, immigration, military authorities etc. Around 25 messages are required, but several of these are sent by the ship agent so it has been set to 20 in this table [MarNIS 2004].

3.2.5 Operational communication

Operational communication is communication between the ship and the owner, charterer, port, port state authorities, or any other party involved in commercial activities related to the ship. This particular section addresses reports that are sent or received during normal passage execution. The communication is typically in a similar form to the mandatory ship reporting.

Table 9 gives an overview of operational communication requirements. The figures are typical for normal cargo ships. Container, RORO, break bulk and passenger ships will typically have significantly higher requirements due to more complex descriptions of “cargo”.

[4] FAL Form - IMO Facilitation Committee's proposed standard formats for ship clearance

[5] ISPS - International Code on Ship and Port Facility Security

Table 9 – Operational communication requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Voyage orders and reports	9600	2000	0,06 %	0,58 %	1,45 %	CO	N
Commercial port call messages	9600	2000		1,54 %	3,86 %	CO	N
Operational reports	9600	3000	0,17 %	1,74 %	4,34 %	CO	N
Weather forecast	9600	5000	0,05 %	0,48 %	1,21 %	CO	N

Voyage orders and reports are messages to or from the ship and the owner, manager and/or charterer. These will typically consist of voyage orders, daily noon reports, arrival and departure reports as well as port call logs and similar. These are today often sent as fax or e-mail.

Commercial port call messages are related to the operations during a port call, ordering services and supplies, arranging for crew exchanges etc. This also includes pre-arrival notifications to the service providers. Some of these messages may be quite large, but normally they are on the order of around 10 Kbytes.

Operational reports are sent between the ship and shore management and may be related to technical issues (engine reports), safety management, various economy and crew reports etc.

Weather forecast is updates to general weather forecasts for the remaining part of the voyage. It is assumed that more detailed data for general routing is processed as part of the extended operational reports (see next main section).

3.2.6 Cargo and passenger communication requirements

Some types of cargo, including passengers, will require or request access to information channels for remote monitoring or control. This is of limited interest in the context of e-Navigation as these services are commercial in nature and the cargo owner or passengers will pay for necessary bandwidth and infrastructure directly or through transport fees.

However, as the users will pay for this service, they will help to make lower cost communication resources available also for other applications. **Table 10** lists some types of communication that are related to passengers or other cargo. In the table it is assumed that VSAT services are used, either through a “normal” 64 kbps link or through higher speed links for more demanding applications.

Table 10 – Passenger and cargo communication requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Cargo telemetry, online monitoring	64000	10000	0,03 %	0,03 %	0,03 %	SP	N
Special ship, data gathering	1500000	100000	53,33 %	53,33 %	53,33 %	SP	N
Passenger infotainment	1500000	100000	54,22 %	54,22 %	54,22 %	SP	N
Payments and inventory	64000	1000	25,00 %	25,00 %	25,00 %	SP	N

Special cargo, like refrigerated containers, may need continuous supervision. The rate and amount of data will depend on number of units that are supervised and type of supervision. The stated figures may be typical for a container ship with about 500 to 1000 monitored containers.

Some ship, e.g., for seismic exploration, do data collection that needs to be transmitted to shore. Again, rates and amounts will vary.

Passengers will often be willing to pay for general Internet access. Figures here correspond to a medium speed asymmetric Internet connection. This is a typical figure for passenger ferries and cruise ships.

Smaller (and large) passenger ships will often have facilities for on-line payments from passengers and integrated inventory management. The figures presented represents an estimate based on ten transactions per second.

Note that all services are flagged as "Special purpose" as it is assumed that each ship will use a dedicated VSAT link for its communication needs and that it will not use common e-Navigation bandwidth.

3.2.7 Crew Infotainment

There is an increasing focus on crew welfare as access to experienced mariners is getting more difficult. One of the most important aspects of this is the crew's access to communication facilities to keep in touch with home and family. Also, crew training can be improved by having access to communication. **Table 11** lists communication services related to crew's communication needs.

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Crew communication to family/home	64000	50000	0,29 %	0,29 %	0,29 %	SP	N
Crew training	64000	50000	0,03 %	0,03 %	0,03 %	SP	N

Table 11 – Crew infotainment requirements

The bandwidth demand for both these services will generally correspond to what is offered. The figures in the table show how much bandwidth is used when the crew has access to one large e-mail per day.

3.3 Possible new e-Navigation services

This section discusses some areas that have been pointed out as possible candidates for being a part of e-Navigation. Mostly, these fall into the categories of "Emergency management", "Additional navigational information" or "Operational reporting". We will also briefly discuss increased crew infotainment requirements.

3.3.1 Emergency management

Recent EU projects, e.g., DSS_DC[6] and Flagship[7] have highlighted the potential benefits of using digital communication during emergencies. This can more accurately transfer information about the actual state and save the emergency management team from much of the voice traffic that is currently going on.

In the context of e-Navigation one can assume that also emergency management will be an important component. Digital communication with continuous and automatic update of all

[6] DSS_DC: Decision Support for Ships in degraded Condition (EU contract SUSTDEV-2002-3.4.2.4.11)

[7] Flagship integrated project: see www.flagship.be.

shipboard and shore details could be a significant contribution to efficient handling of emergencies at sea.

Table 12 – Additional emergency management requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	PU/CO	Dedic.
Communication to other ship	64000	5000	33 %	33 %	33 %	SP	N
Communication to SAR	64000	5000	33 %	33 %	33 %	SP	N
Communication to owner's office	64000	5000	33 %	33 %	33 %	SP	N

There are basically three types of communication one needs to consider:

1. *Communication with other ships in the area*. Some digital exchanges can be done via AIS data, e.g., position and navigational status. Most other communication would probably be based on voice. However, simple web based applications to maintain checklists and action plans as well as overall status of ship and passengers would be very useful. It will according to estimates in above projects not require more than a 64 kbps data link, although higher capacities would be useful.
2. *Communication with Search and Rescue (SAR).* This is similar to item one, except that more detailed digital information most likely would be picked up by the SAR organization directly from the owner's office, rather than from the ship itself.
3. *Communication to owner's office.* This is a critical issue as the owner will set up an on land emergency management organisation that has access to the required resources to assist the ship beyond what the SAR organisation can offer. The above mentioned EU projects have suggested that this would require a digital capacity at least on the order of 64 kbps.

Totally, the estimate is that this would use about one third of the capacity of a 64 kbps satellite link, with sufficient capacity to spare for voice and other communication such as, e.g., still pictures.

One should note that the first item can be serviced through the use of terrestrial communication systems even at sea, if at least one of the ships in the area is equipped with suitable equipment for setting up a local network.

Note also that conventional voice communication with SAR and shore would be additional to the above listed services.

3.3.2 Position and safety reporting

New services will become available also in this area, but one can expect that these will be based on dedicated carriers as is currently the case in this group. Typical examples of this are new services related to GALILEO[8], various position signal augmentation systems or satellite based AIS receivers.

Currently we do not see that these services will put any great demand on carriers and we also expect that most of the services may use dedicated carriers. Thus, from the point of view of this

[8] Proposed European GNS system

report, they will most likely not contribute to the selection of specific data carriers for e-Navigation.

3.3.3 Additional navigational information

This is perhaps the most obvious area for extending communication services into e-Navigation domain. The table lists some possible services that have been identified as candidates for inclusion in the e-navigation concept.

Table 13 – Additional navigation requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
VTS coordination	64000	5000		1,45 %	3,62 %	PU	N
MIO	64000	10000	0,17 %	1,04 %	1,04 %	PU	N
PPU - VTS image	128000	100000		62,50 %	62,50 %	PU	N
Real time met-ocean	64000	100000	0,35 %	0,35 %	0,35 %	PU	N

IALA has published a report on the future of maritime radio communication services [IALA 2005]. It does not identify any particular new requirements for digital communication services, but lists some challenges to current technology:

- Larger commercial pressure on communication channels and frequencies
- Larger pressure and greater need for AIS bandwidth
- In general, more need for communication from ships, both spoken and digital

One area that is particularly mentioned is the VTS[9] and its increasing need for voice communication over VHF. It is obvious that much of this communication could be exchanged as digital information if suitable facilities existed. This would allow both ship and VTS to automatically exchange information about traffic situation, recommendations and status and by that lowering bandwidth demands as well as workload on operators.

The concept of Maritime Information Objects (MIO) [Alex 2003] is also related to the challenges pointed to by IALA. An IMO is a dynamic object that can be placed on an electronic chart and updated in real time. This will obviously require communication to the ship for the MIO updates. The MIOs that are currently defined are:

- Ice Coverage (*)
- Meteorological (*)
- Tides/Water Levels
- Current Flow
- Oceanographic data (*)
- Marine Habitats
- Environmental Protection
- Vessel Traffic Services (VTS)

[9] VTS – Vessel Traffic Services (Maritime traffic supervision and service centre)

The MIOs marked with a (*) has already been developed and registered on the open ECDIS Forum [HGMIO 2004]. Each MIO will typically require the periodic transmission of identity, type, position (x,y,z) and status. Exactly how much data this will amount to, obviously depends on the type of MIO.

Another area where digital transmission of data is starting to make an inroad is on portable pilot units (PPU). These are self contained navigational systems carried onboard the ship by the pilot. As an example, the AD Navigation ADX unit[10] can connect via broadband to the VTS to show the traffic image to the pilot. Many other applications of such communication can be envisaged, including remote access to CCTV pictures, pilot oriented MIOs etc. It is also obvious that similar services could be made available to ships, e.g., with pilot exemption.

Real-time metocean data is also obviously an area which should be included in e-Navigation. This is closely related to MIOs, but is listed separately here. The reason is that sizes of data files are larger and that they most likely will be transmitted in other formats than the MIO (ECDIS compatible).

3.3.4 Mandatory reporting

As e-Navigation will require more bandwidth one can also expect that requirements to mandatory reporting will increase. It can be argued that this is most likely to happen with respect to environmental and security data. However, also arrival and departure reports may increase somewhat to provide for a more efficient handling of ships in ports.

Table 14 – Extended mandatory reporting requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Ship reporting	64000	1500		0,52 %	1,30 %	PU	N
Coast state notification	64000	5000		1,74 %	4,34 %	PU	N
Port arrival notification	64000	5000		1,74 %	4,34 %	PU	N

In this paper we have estimated roughly a doubling of the messages, but we have increased the bit rate beyond what we used in the first example.

3.3.5 Extended operational reporting

As has been pointed out by IALA, e-Navigation should cover both public and commercial services. Availability of better communication facilities and better integration of onboard systems certainly creates possibilities in this area.

Table 15 gives an overview of some possible new operational reporting services and their communication requirements. The data are based on experience from work with information technology solutions for owners and charterers, but also from the MarNIS project [MarNIS 2006]. The figures are typical for standard cargo ships. Container, RORO, break bulk and passenger ships will typically have significantly higher requirements due to more complex descriptions of "cargo".

[10] AD Navigation AS, www.adnavigation.com.

Table 15 – Extended operational communication requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Commercial port services	64000	10000		2,89 %	7,23 %	CO	N
Navigational data update (ENC)	64000	100000	0,14 %	1,45 %	3,62 %	CO	N
Operating manuals, documents	64000	10000	0,01 %	0,14 %	0,36 %	CO	N
External maintenance and service	64000	50000	0,14 %	1,45 %	3,62 %	CO	N
Telemedicine	64000	1000000	0,29 %	0,29 %	0,29 %	SP	N

Commercial services to ships approaching or in the port will soon be a reality in Singapore, where a WiMax network is being deployed. In addition to providing general purpose Internet connection, one also expects that the network will provide specialized serviced directed at the ships. Services that are envisioned are among others[11]:

- Content delivery to consumers at sea, e.g. video channels, ship schedule information, video-on-demand. Specialised ship-shore applications, e.g. regulatory reporting, maritime service booking
- Automated diagnostics and maintenance tools, e.g. ship status reports, maintenance testing/monitoring etc.
- Enhances safety, security and traceability of goods and personnel, e.g. surveillance, personnel and goods tracking.
- Enhances logistics information flow and visibility in operations, e.g. track-and-trace, transport management.
- Enables unmanned operators in remote locations, e.g. Automated Guided Vehicles and Remote Crane Controls.

Updates of navigational data are mostly relevant in conjunction with port calls. Normally the Master wants to update data when preparing for the next voyage. This will mainly consist of updates to electronic navigational charts (ENC), notices to mariners and other information related to navigation. Also, operational information about the ports is included in this category.

Updates of operational documentation and databases would also normally take place in port. This is general updates to onboard resources used in day to day operations. This may include operating manuals, technical manuals or other data needed on the ship.

External maintenance and service represent provision of second or third party services to the maintenance or supervision of onboard equipment. This may be on-line monitoring or periodic reporting combined with on demand intervention. Transmissions may include measurements, pictures or video. The figures presented here is just an indication of the relevant data requirements. This will vary widely, dependent on type of service.

Telemedicine services may also use from almost zero (except for voice) to very high data volumes when it is required. In general, one should probably have access to at least transmission of still pictures and certain measurements.

[11] Wiseport information at http://www.ida.gov.sg/Programmes/20071030141818.aspx?getPagetype=34

One can probably expect that this type of infrastructure, which is also useful for other e-Navigation services, can host a long range of commercial services similar to the ones mentioned above.

3.3.6 Cargo and passenger communication

This group can be expected to remain unaffected by the introduction of e-Navigation although communication demands in this area can in any case be expected to grow at least as much as more specific e-navigation related communication.

3.3.7 Crew infotainment

Crew demands for communication can be expected to increase as the society at large becomes more accustomed to at any time be able to contact friends and family. Basically, one can probably not put any limit on this demand as it will at all times be as great as or even greater than what is available. Below is indicated how bandwidth demand will increase if crew gets an allowance of 10 MBytes per day instead of 50 kByte as in the example in section 3.2.7.

Table 16 – Extended operational communication requirements

Service	bps	Bytes	Tot BW OS	Tot BW Co	Tot BW PA	Type	Dedic.
Crew communication to family/home	64000	10000000	57,87 %	57,87 %	57,87 %	SP	N
Crew training	64000	10000000	5,79 %	5,79 %	5,79 %	SP	N

4. Available and emerging ship communication technology

4.1 Satellite systems

Satellite systems will continue to be important for shipping at the high seas. Also in shore areas will satellites be important, particularly for position reference systems and similar services. Today, there are basically two types of systems that are available for bidirectional high capacity (voice and e-mail) communication:

- *LEO:* Low earth orbit systems where Iridium is the main operator. However, one can also make use of systems like Orbcomm[12] and Globalstar[13] for simpler messaging applications.
- *GEO:* Geostationary earth orbit systems like Inmarsat and various commercial providers giving VSAT or direct IP access via their services.

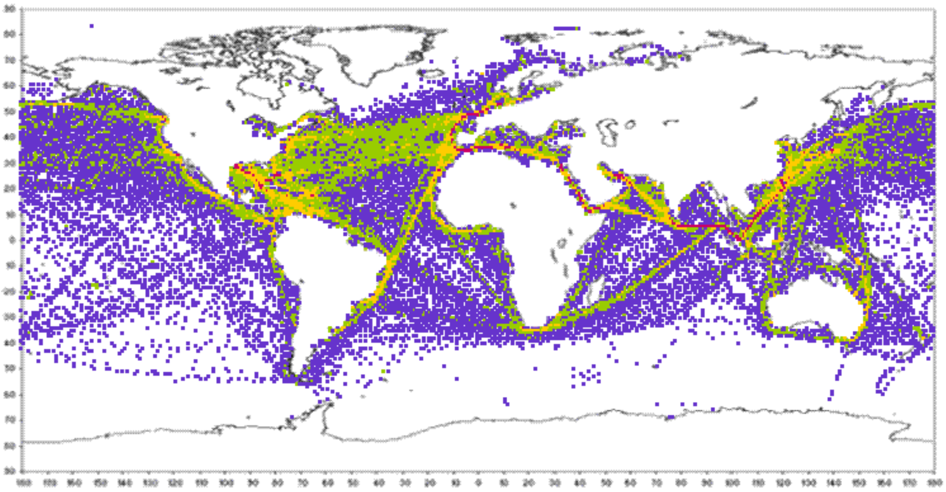
A general problem for maritime applications is that the density of users is relatively low on the high seas. This is illustrated in the AMVER[14] plot below where white areas represents area with no reports from a ship last month, blue dots are areas with less than four reports per month and so on. As one can see, there is a definitive challenge in providing cost effective world wide coverage to shipping.

Another problem with high capacity satellite communication, particularly when based on GEO systems, is that one normally requires a dish type stabilized antenna. It can prove difficult for a

[12] http://www.iridium.com/
[13] http://www.globalstar.com/
[14] Atlantic Merchant Vessel Emergency Reporting http://www.amver.com

ship at high latitudes with some roll or pitch movement to maintain the connection to the satellite. Also, higher frequencies which tend to be used in newer services to provide more bandwidth, are susceptible to disturbance from rain.

Figure 5 – AMVER Plot April 2008



However, developments in technology continues and while it may be more expensive to provide world wide coverage at sea than similar coastal services, there is no reason to doubt that satellite services will provide any bandwidth that the market demands. Thus, it will not be a limiting factor for e-Navigation.

4.2 New shore based systems

Since around 2000, a series of new long range digital technology has become available and able to provide relatively high data bandwidths also to maritime users. The following sections will briefly look at some of these technologies. The table below summarizes the main characteristics.

Table 17 – Wireless long range technology

System	Frequency	Range	Bandwidth per cell
WiMax, IEEE 802.16	2.3, 2.5, 3.5GHz	< 50 km	70 Mbps
CDMA-450	450 MHz	< 70 km	4 Mbps
Digital VHF (Existing)	156 MHz	< 130 km	21.1 kbps (25 kHz)
Digital VHF (Modified)	156 MHz	< 130 km	153.6 kbps (50 kHz)

We have not included GSM type communication in this overview although it may certainly be used in e-Navigation applications. The current structure of high number of national service providers, need for roaming agreements and so on makes it difficult to deploy this as a standard communication mechanism. However, this can be done through public-private partnership agreements.

4.2.1 WiMax – IEEE 802.16

WiMax (**W**orldwide **I**nteroperability for **M**icrowave **Ac**cess) is a fairly new “Metropolitan Area Network” (MAN) that can deliver digital services with high quality at long ranges. It has been deployed several places, notably on the coast of Norway and in the port of Singapore. However, most deployments are currently for non-mobile services. WiMax operates currently on licensed frequencies which mostly have been bought by private operators. There are plans to deploy WiMax also in new frequencies of which some may be license exempt [WiMax].

WiMax is perhaps the most obvious choice for a shore based e-Navigation system. However, frequencies and areas are owned by different operators in different countries and it may be a challenge to standardise the services provided.

On the other side, it may be possible to establish a standard service in new frequency bands. This could be done by reserving some frequencies for public use or by requiring a private-public cooperation when these frequencies are sold. In particular, the frequencies 450 MHz to 470 MHz and 790 MHz to 806 MHz have been allocated to mobile services in all the main regions [WRC-07].

4.2.2 CDMA-450

CDMA-450 is an adaptation of the CDMA-2000 standard to the 450 MHZ band. This band was formerly used for mobile services, such as NMT 450 mobile phones. It can provide reasonable services in relatively narrow frequency bands and is well suited to long range mobile Internet access.

This may perhaps be an alternative to WiMax, but it has the same constraints as have been discussed above.

4.2.3 Digital VHF in Norway

Digital VHF has been deployed along the Norwegian coast by the company Telenor. They use nine standard 25 kHz channels from the marine band and can merge these into one digital 225 kHz channel with a maximum duplex bit rate of 133 kbps. Each channel can carry 21.1 kbps individually [ITU M.1842].

This design has met with some resistance, e.g., from IALA that rather would see other technologies deployed [eNAV2] as the current system may interfere with other marine VHF services and in particular AIS. The proposed alternative is briefly described in the next section.

This system could be very attractive for e-Navigation as the frequencies are already allocated to maritime mobile use. As the discussion in the previous chapter showed, there may be enough bandwidth in this type of system to implement all or most of the discussed services.

4.2.4 Modified digital VHF

The proposed alternative to Telenor’s solution uses another modulation scheme to decrease interference. This modulation scheme also provides a higher bandwidth. The current proposal [ITU 5B/19] gives 153 kbps over a 50 kHz channel (two old VHF channels).

Again, the frequencies are already allocated to mobile maritime use, which may make this a simpler proposal to implement internationally.

4.3 Coverage in Polar regions

Increasing activity in the Arctic region both from shipping and hydrocarbon exploration and developments also makes the problem of radio coverage in this sea area more acute. Shore based systems will obviously not be able to cover the sea areas although they could be alternatives for the northeast and north-west passages.

Three options seem to be possible:

1. *LEO systems*: Iridium or other LEO systems could be used to provide coverage. This could also be interesting from the point of view of providing AIS coverage at sea.
2. *Molnyia orbits*: Highly elliptic polar orbits may be used to provide coverage also in the northern regions. Three satellites should be sufficient to give 24 hour coverage.
3. *HF based digital communication*: Due to low bandwidth requirements in these areas one could possibly make do with a HF or MF solution.

This issue is more general than just e-Navigation, but it is included here to point out this particular problem so that it can be considered in any new developments for e-Navigation.

5. Comparison of communication solutions

5.1 Private or public service

One important issue in the selection of new carriers for e-Navigation data is whether the service should be private or public. Today and in the foreseeable future one can illustrate the available communication means as in **Figure 6**. There are two main groups of carriers: Public services implemented through international agreements and basically available for free; and private services that require some form of payment.

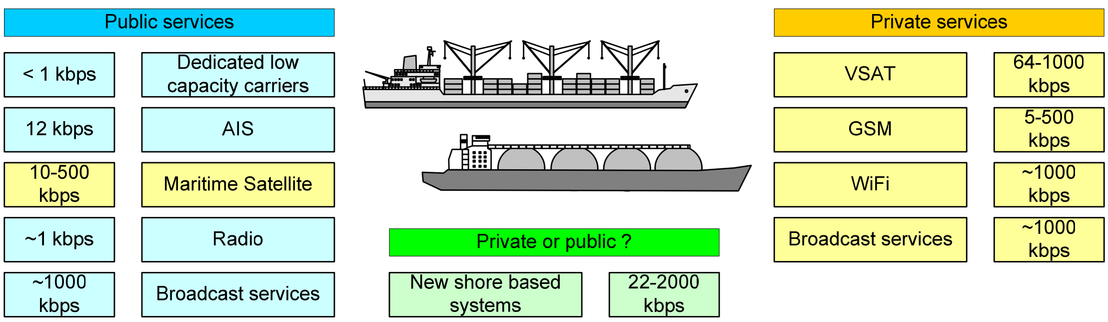


Figure 6 – Maritime communication facilities

A detailed description of current and emerging radio communication facilities was developed through the MarNIS project and described in [MarNIS 2004]. Data in the following sections is largely taken from that report.

5.1.1 Public services

The public services have been established over several years, from the first days of radio communication. Many of them are dedicated to special services, but a few are more general in nature and should be considered for future use in e-Navigation:

- *AIS:* This is basically a general purpose many to many communication system. It uses two channels of 9.6 kbps where each message of 256 bits can carry 168 bits of payload. Total capacity is thus about 12.6 kbps. This has to be shared between all ships in a relatively large cell. In addition, as its main purpose is to send position fixes for ships, there is in general little spare capacity for other purposes – particularly in densely trafficked areas.
- *Satellite services:* Inmarsat C and Fleet 77 are currently approved for GMDSS[15] use. Although it is in a sense a public service, usage of the general digital communication facility is fairly costly. Thus, it is not clear if it can be used for extended e-Navigation services. SafetyNet messages, position reports and safety alerts are generally "free", but have very limited size and capacity.
- *Broadcast services:* As has been mentioned, weather forecasts are transmitted as free broadcasts over satellite. This facility could also be extended to cover other aspects of e-Navigation. Also VHF, HF and other radio bands can be used for this. However, current digital radio broadcasts (e.g., NAVTEX[16] and weather) have very limited bandwidth.

We will come back to the requirements for e-Navigation, but it is fairly clear that the current public services may have problems in supporting any significant new demands.

5.1.2 Private services

There is a wide range of private communication services available today. The most relevant are shown in the figure and described below.

- *VSAT*: Private satellite communication facilities using "Very Small Aperture Terminals", i.e., small stabilized antennas. Bandwidths in the range from 64 kbps to several mbps can be used, at a cost. Another drawback is that few service providers have global coverage. Good coverage at reasonable prices is normally only available in areas with relatively high density of users. However, VSAT seems to be a fast growing solution for commercial messaging and crew infotainment.
- *GSM:* Mobile telephone is a good alternative for ships that trade close to the coast and with a limited number of ports to call in. Otherwise, the roaming costs associated with GSM and particularly high prices for digital transfers are serious obstacles. Coverage may also be a problem.
- *WiFi:* Wireless Internet networks are available in some ports. This is currently being supplemented with WiMax, that typically has much longer range and which is may be more suitable for ship use. Drawbacks are very localized and limited availability.
- *WiMax:* WiMax frequencies are also mainly owned by private companies which also may make it more difficult to use for e-Navigation.
- *Broadcast services:* Television signals and weather forecasts are already being broadcast to ship and DVB-RCS is starting to be deployed as an alternative to VSAT. This medium

[15] GMDSS – IMO specified set of services for Global Maritime Distress and Safety System
[16] NAVTEX – Narrow Band Direct Printing of international and national maritime warnings

may also be of interest to e-Navigation services as it may offer a low cost alternative for transmission of large volumes. Broadcast via terrestrial radio is also an alternative, but digital bandwidth will in most cases be limited.

One serious problem with private service providers is that there is a cost associated with data transmission. This may be an obstacle to international acceptance of e-Navigation strategies in IMO.

5.2 Comparison of terrestrial systems

The most promising terrestrial systems are GSM type technology, digital VHF and WiMax. The latter can be divided into operation on 790 MHz and the more conventional systems at 2.4 GHz and up.

Basically all systems have sufficient capacity to be used in maritime applications. However, range will normally be better the lower the frequencies are. This gives digital VHF a great benefit as Telenor already has shown ranges up to 60 nautical miles. An interesting alternative here is WiMax over 790 MHz which should give good range also for this service.

The other critical factor is international standardization. Digital VHF is clearly the best option here as these frequencies already are allocated to mobile maritime use. Getting a maritime service at 790 MHz may also be possible, but requires quite a bit of international work if this is to be established as a standard. Otherwise, one will have to rely on private service providers.

5.3 Satellite or terrestrial systems

Another issue which is an important parameter is if new e-Navigation services should be based on satellites or on shore infrastructure. The previous discussions in this document have pointed out some benefits and some drawbacks to each.

Table 18 – Some differences between satellite and terrestrial

Issue	Satellite	Terrestrial
Ocean coverage	70º S to 70º N	< 120 km from coast
Sensitivity to ship movements	Higher	Lower
Sensitivity to shadows in fjords etc.	Higher	Lower
Available bandwidth	Higher?	Lower?
Real-time performance	300 ms sec delay	No delay

The bandwidth issue is very dependent on frequency use and what modulation one chooses. Satellites will in many cases provide more bandwidth, particularly when operating in Ka and Ku bands, but this will also increase problems with rain fading.

Note also that LEO satellite systems such as Iridium overcomes many of the problems listed here. However, these are privately operated at relatively high cost and may not be suitable for that reason.

5.4 Some criteria for selection

The following sections list some criteria that can be used for selecting a carrier for e-Navigation services. The criteria are summarized in the table.

Table 19 – Some criteria for selection

Issue	Satellite	Terrestrial	Private	Public
International standard	O	O	O	O
Full world coverage	+	--	O	O
Load balancing coast/sea	--	++	O	O
Security	+	-	O	O
State ownership	-	+	--	++
Cost infrastructure	+/-	-/+	O	O
Minimum duplication	++	--	O	O
Cost ship	--	++	O	O
Benefit for developing countries	-	++	O	O
Coastal fleet support	--	++	O	O
Safety	O	++	O	O

The coding used is ‘O’ for no particular preference, ‘+’ for better than average support, ‘++’ for very good support and, correspondingly, ‘-’ and ‘--’ for less than average support.

5.4.1 International standard

It would be very beneficial if the e-Navigation services could be provided as a standardized international service.

This is obviously possible if the services were provided through an Internet portal where each ship could select its own communication service provider. However, it may not always be possible for a ship to get access to the Internet as this typically will be relatively costly.

Another solution would be to develop an international standardised communication service akin to AIS, but with an Internet type packed switched communication facility.

None of the alternatives will give any particular benefit compared to the others.

5.4.2 Full world coverage

The issues here are mainly coverage in Polar regions and high seas. It is clear that a terrestrial service is not able to cover sea areas and that it has to be supplemented by satellite in these cases. However, this still leaves arctic areas as a challenge.

The only likely solution is to combine different communication systems for the different applications. Note also that Antarctica is less of a problem as the continent makes it unnecessary to provide satellite coverage for marine applications in the high latitudes.

5.4.3 Load balancing coast/high sea

As Chapter 3 showed, there is a great difference in communication demands near coast or in port and at high seas. A combined satellite/terrestrial system would be able to utilize that difference to get a better load balancing.

5.4.4 Security of digital communication links

Security will in most cases be related to harmful intervention from third parties that either fakes e-Navigation data or jam the signal (denial of service attacks via Internet is one variant of this).

It is not clear if any of the different options have any special benefits in this area, except that one could argue that shore infrastructures are more susceptible to direct physical attacks.

5.4.5 Coastal state ownership of infrastructure

As the coastal state (or group of states) will be responsible for the content of the e-Navigation data, one should in principle also ensure that they have full ownership and control of the infrastructure. This gives a negative mark on private systems and, thus, also on satellite systems as they in most cases must be operated by a joint venture.

5.4.6 Cost of infrastructure

The cost of a WiMax base station is estimated at around EUR 50 000 for equipment and VSAT equipment for backhaul to main networks [MarNIS 2006c]. In addition one will have costs also for installing the system, for maintenance and for operation. One can probably expect similar figures for VHF type systems. We do not have cost figures for satellite systems, but it is assumed that these will be significant.

However, if satellite capacity can be leased from international providers, it is also clear that infrastructure costs would be greatly reduced compared to building any form of infrastructure oneself.

5.4.7 Minimize duplication

If a premise is that one shall try to minimize duplication of carriers, then satellite is the only option. However, for safety reasons it may be a good idea to use more than one system for safety functions. Currently, one can claim that this is the case with the duplication through both the COSPAS/SARSAT and the Inmarsat systems, but it can be argued that this should also extend to voice or data communication which is beyond the capabilities of COSPAS/SARSAT.

5.4.8 Cost for ships

For ships one can expect that costs of equipment are significantly lower for WiMax and VHF compared to VSAT. Digital VHF equipment is estimated to cost around EUR 2 500 and monthly payment for a 21 kbps link around EUR 400 by Telenor. Somewhat higher costs may be assumed for WiMax equipment. A ship installation for satellite communication can easily cost up to ten times as much.

5.4.9 Benefit for developing nations

For developing nations with little possibilities for installing expensive equipment on the ships, it will most likely be highly preferable to develop a terrestrial system – particularly if this is built on international standard. This will give a low threshold for getting national ships, e.g., fishing vessels and ferries, into the e-Navigation network while the infrastructure also caters for international obligations to passing ships.

The network being privately owned or not does not matter in this context. Private operation can be assumed to reduce initial investments while increasing operational costs.

5.4.10 Use by national fleet / coastal ships

Many national ships do not have satellite communication equipment and will have to rely on terrestrial systems as the situation is today.

5.4.11 Safety by providing more than one GMDSS carrier

It has been strongly argued that VHF based DSC for safety purposes needs additional support to provide an alternative to GMDSS safety alerts over Inmarsat [Dunstan 2008]. The arguments used for this were mainly those two independent systems increases the chances that at least one will work in an emergency and that many smaller vessels did not have access to Inmarsat services at all.

VHF based DSC have significant problems today with the service provided as coastal radio stations are removed and automation increased. There have also been a relatively high number of false alerts on this system.

By providing added services over VHF or another terrestrial carrier the system will be much more used and problems decrease as familiarization increases. Also, as has been pointed out above, e-Navigation consists of a complement of public and commercial services where the commercial part can help to finance infrastructure and operations.

Thus, it is can be argued that a terrestrial based system will significantly enhance maritime safety.

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7. Annex A: Detailed analysis of communication requirements

The following Annex presents details for the numerical analysis of communication requirements as presented in preceding chapters.

7.1 General overview and method

The numerical analysis has divided communication requirements into 6 main groups which have been repeated twice, one time for current situation and one time as a forecast for additional future e-Navigation services. The 6 main requirements groups are explained in section 2.3, but are repeated here for convenience:

1. Emergency management
2. Position and safety reporting
3. Additional navigational information
4. Mandatory ship reporting
5. Operational reporting
6. Cargo and passenger
7. Crew infotainment

For each group (including the future e-Navigation scenario) a number of services are identified and communication requirements for these analyzed. The outcome of this is in the "Total bandwidth" (Tot BW) columns.

Three cases for total bandwidth consumption have been used as listed in the below table.

Table 20 – Ship count for areas

Area	Number	Description
OS	50	Open sea
Co	150	Coastal area
PA	250	Port approach

All these counts refer to an estimated maximum number of ships that are within a "radio cell", i.e., worst case number of ships that can communicate with each other or shore and which will demand bandwidth for their data traffic.

The fixed data for each service are listed in the below table. The "Table" column specifies if the parameter value can be found in the main table in Chapter 3 or in the Annex table (below).

Table 21 – Fixed parameters used in analysis

Parameter	Table	Description
Bit rate (bps)	M	Capacity of channel, in bits per second
Message size (Bytes)	M	Typical mean size of message, weighted if relevant for differences in incoming and outgoing messages
Hz in OS	A	Estimates input message frequency in open sea scenario
Hz out OS	A	Estimates output message frequency in open sea scenario

Hz in Co	A	Estimates input message frequency in open sea scenario
Hz out Co	A	Estimates output message frequency in coastal scenario
Hz in PA	A	Estimates input message frequency in open sea scenario
Hz out PA	A	Estimates output message frequency in coastal scenario
Mode	A	Specifies if service is unicast (UC) or broadcast (BC)
Type	M	Specifies a commercial (CO), public (PU) or special service (SP)

For each service in each requirement group, an estimate of incoming and outgoing messages as well as message sizes has been made. These estimates are based on general knowledge about the service and what documentation we have been able to collect.

The annex will present the estimates valid for one ship in the specific area for each of the requirements groups. Where necessary, additional details will be provided regarding how the results were arrived at.

For the service utilization presented in the main chapter of the report, the message frequencies have been converted to utilization through the following formula:

$$U = f_{in} * (m == "UC" \&\& t <> "SP" ? \ N_a : 1) * \delta b + f_{out} *(t == "SP" ? 1 : N_a) * \delta b$$

Where the symbols have the following meaning:

- U : Utilization as listed in the main table (percentage of total bandwidth available).
- f_{in}: Input message frequency as listed in annex tables.
- *(m == "X" ? A : B):* This expression means that if *m* equals *X* then the value is *A*. Otherwise, the value is *B*.
- *==:* Test for equality (see above).
- *<>:* Test for inequality (see above).
- *&&:* Boolean and operation (see above).
- *m*: Transmission mode (broadcast, unicast or special purpose) as listed for the service in the main table.
- N_a: Number of ships in area *a* as listed in Table 20.
- *δb:* Share of bandwidth for one message as defined by message size in bits (#bytes times eight), divided by bandwidth (bps).
- *t*: Type of service as specified in main table.
- f_{out}: Output message frequency as listed in annex table.

Basically, the formula multiplies the ship's specific traffic requirements with appropriate factors for the number of ships in the area, based on if the traffic will be generated by all or not.

The figures presented and the results calculated are bound to be fairly approximate, but the whole intention of the exercise is to give a better idea of what bandwidth one may require for implementation of e-navigation. We will come back to a discussion of this in Chapter

7.2 Emergency management

The estimate for traffic is set to one outgoing message per 100 days for all services. This is probably on the low side as there is some false alerts and as there also is quite a few ships in each area. The service is defined as special purpose so bandwidth requirements are not multiplied with the number of ships.

Table 22 – Traffic details for emergency management

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
DSC (via MF, HF or Inmarsat)	UC		1,16E-07		1,16E-07		1,16E-07
EPIRB (406 MHz COSPAS SARSAT)	UC		1,16E-07		1,16E-07		1,16E-07
SSAS (Inmarsat)	UC		1,16E-07		1,16E-07		1,16E-07

As was mentioned in the main chapter, there is much more traffic related to emergency management than this, but this is voice traffic and out of scope in this context.

7.3 Position and safety reporting

This is a fairly demanding group of services related to the bandwidth they are allocated. In particular AIS can be expected to be utilized quite heavily in congested waters. The frequencies used for message transmission is based on available literature and estimated as well as could be done.

Table 23 – Traffic details for position and safety

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
GNSS (GPS, Glonass, Galileo)	BC	0,50000		0,50000		0,50000	
AIS position report (msg. 1, 2, 3)	UC		0,08333		0,16667	0,00278	0,16667
LRIT position report (Inmarsat)	UC		0,00005		0,00005		0,00005
DSC (via MF, HF or Inmarsat)	UC	0,00028	0,00028	0,00083	0,00083	0,00139	0,00139
AMVER (position report)	UC		0,00005		0,00005		0,00005

GPS – Global Positioning System should be well known. It transmits certain data that can be transformed into time and position information. GNSS (Global Navigation Satellite System) is a more general term that includes GPS, GLONASS and the future Galileo systems. The high demand on these systems just indicates that the dedicated carrier is utilized as far as possible. It has not any other purpose than sending position data.

AIS – Automatic Identification System is a VHF based position (and other information) reporting system that is used for both navigational and security purposes. The design criteria for this service are based on worst case traffic patterns in highly congested waters, such as the English Channel and the Malacca Strait. This is verified by these calculations. The ingoing traffic percentage in port approach is due to an estimate of a certain number of messages being sent from the AIS base station in conjunction with VTS operations. Otherwise a mean rate of 800 messages per hour per ship is used.

LRIT – Long Range Identification and Tracking is similar to AIS, but intended for distances up to 1000 nautical miles from shore. It is normally sent via Inmarsat.

DSC – Digital Selective Call is a digital communication mechanism on VHF Channel 70 that is, among other things, used to set up VHF calls. It can be expected that demand on this service goes up when the ship approaches port.

AMVER[17] is not a mandatory service, but is included here as it is more related to these than to purely operational messaging. These services require a short report from the ship each 4 to 6 hours. The service will most likely use Inmarsat.

Previously, also the radio telex service could be included in this list, but this service is now mostly discontinued.

7.4 Additional navigational information

If we do not include enhanced services that are discussed under the e-Navigation section, this group represents relatively limited demand on communication.

Table 24 – Traffic details for additional navigation

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Differential GNSS (RTCM)	BC	0,01667		0,01667		0,01667	
AIS (other messages, AtoN)	BC			5,00000		5,00000	
NAVTEX (MSI)	BC	0,00167		0,00167		0,00167	
SafetyNET (MSI over Inmarsat)	BC	0,00167		0,00167		0,00167	
Weather fax	BC	0,00012		0,00012		0,00012	

Differential GPS is received as data packets [RTCM 194] from various suppliers over radio, satellite or even Internet. Communication bandwidth is dependent on accuracy requirements, but even for high accuracy real time corrections one will normally require from 0.5 to 2 kbps. For normal ship board use, one may drop it altogether or manage with wide area augmentation service at low update rates.

AIS can carry information about hazards to navigation in addition to ship positions. It can also carry information on general aids to navigation (AtoN) such as lighthouses or buoys. As these objects do not move, a relatively low update frequency is needed. However, it must be high enough to update transiting or arriving ships on time. In this scenario it is indicated that messages increase as a vessel approaches the coast.

NAVTEX is a HF based narrow band direct printing system transmitting nautical warnings to ships. This can typically include weather, ice or ship wrecks. Only very low bandwidth is available so the number of different messages over a day is typically less than hundred.

SafetyNet is an alternative service to NAVTEX, but over the Inmarsat C Enhanced Group Call service.

[17] Automated Mutual Assistance Vessel Rescue System, www.amver.com.

Weather fax is not really a digital service, but the figures here represent approximate data for a good resolution picture (1200 lines by 1280 binary pixels). This is a general broadcast service and only limited parts of the data is required by the navigator.

One could also include weather data here as the Master is required to assess weather forecasts before and during a voyage. However, in this context the weather data will normally be weather fax or radio broadcasts. Digital weather data for routing purposes is included in the operational section. The same applies to navigational data updates.

7.5 Mandatory ship reporting

The data are based on experience from work with information technology solutions for owners and charterers, but also from the MarNIS project [MarNIS 2006].

Table 25 – Traffic details for mandatory reporting

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Ship reporting	UC				0,00002		0,00002
Coast state notification	UC				0,00005		
Port arrival notification	UC				0,00023		0,00005

Frequencies used are two per day for ship reporting, four per day for coastal state (going in and out of VTS areas) and one port call a day (enter and leave) with a total of 20 messages sent in costal areas before arrival and 4 sent during port approach (and departure).

As also the ship operator and agent are involved in these processes it is difficult to give accurate estimates here.

7.6 Operational reporting

The data are based on experience from work with information technology solutions for owners and charterers, but also from the MarNIS project [MarNIS 2006].

Table 26 – Traffic details for operational reporting

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Voyage orders and reports	UC	0,00001	0,00002	0,00001	0,00002	0,00001	0,00002
Commercial port call messages	UC			0,00003	0,00006	0,00003	0,00006
Operational reports	UC	0,00003	0,00003	0,00003	0,00003	0,00003	0,00003
Weather forecast	UC	0,00001		0,00001		0,00001	

Frequencies used are one voyage report in and two out each day in all areas. Commercial reports are somewhat more frequent and more common in coastal areas and port approach. Operational reports are independent of area, about three each day. Weather forecasts are assumed to come once a day in all areas.

7.7 Cargo and passengers

Message frequencies are shown in the table. The data is very specific for certain ships and will normally not have any impact on e-Navigation one way or another.

Table 27 – Traffic details for cargo and passenger data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Cargo telemetry, online monitoring	UC		0,00028		0,00028		0,00028
Special ship, data gathering	UC		1,00000		1,00000		1,00000
Passenger infotainment	UC	1,00000	0,01667	1,00000	0,01667	1,00000	0,01667
Payments and inventory	UC	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000

The frequencies used are once a day for telemetry and once a second for all others except passenger infotainment where outgoing is set to once a minute. This is to reflect the typical use case with an asymmetric data communication typically used in personal Internet communication.

7.8 Crew infotainment

Crew access to e-mail and Internet is necessary to recruit competent crew today and in the future. The data used in the table in the main section corresponds to one relatively large e-mail per day per crew (20 crew assumed).

Table 28 – Traffic details for crew infotainment data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Crew communication to family/home	UC	0,00023	0,00023	0,00023	0,00023	0,00023	0,00023
Crew training	UC	0,00002	0,00002	0,00002	0,00002	0,00002	0,00002

Crew training data uses an assumption of a corresponding e-mail message each 10 days to and from a shore centre. These data is fairly typical for ships that offer limited access to e-mail for their crew.

7.9 Future e-navigation services – Emergency management

Emergency management is in principle independent of it taking place on sea or close to the coast except that communication means could be different. However, in most cases, if the ship has sufficient satellite capacity, one would most likely use the "standard" communication means to avoid unexpected problems with systems that may not have been included in drills.

Thus, for the purposes in this report, emergency management will obviously be an important part of e-Navigation, but will probably not have a significant influence on selection of data carrier.

The figures used in the table approximates a web based distribution of data from the ship in distress with one update every two seconds going out and data from other ships coming in approximately twice a minute.

Table 29 – Traffic details for emergency management data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Communication to other ship	UC	0,03333	0,50000	0,03333	0,50000	0,03333	0,50000
Communication to SAR	UC	0,03333	0,50000	0,03333	0,50000	0,03333	0,50000
Communication to owner's office	UC	0,03333	0,50000	0,03333	0,50000	0,03333	0,50000

7.10 Future e-navigation services – Additional navigational information

The frequencies that are used in this paper are shown in the table below. It is based on ten messages per day per ship for VTS coordination in coastal and port approach. MIOs are estimated at five per hour at sea and 30 per hour close to coast and in port. PPU VTS images are estimated to be transmitted each 10 second on a fairly high capacity data link. It is clear that such a service will require high update rates and volumes of data. Metocean data is estimated to be sent once each hour.

Table 30 – Traffic details for additional navigational data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
VTS coordination	UC			0,00012	0,00012	0,00012	0,00012
MIO	BC	0,00139		0,00833		0,00833	
PPU - VTS image	BC			0,10000		0,10000	
Real time met-ocean	BC	0,00028		0,00028		0,00028	

7.11 Future e-navigation services – Mandatory ship reporting

The frequency has been increased to one outgoing message per hour for coastal and port approach areas. In open sea one will probably also see an increase in reporting, but this will be more to supervise the position and status of the ship.

Table 31 – Traffic details for additional mandatory report data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Ship reporting	UC				0,00028		0,00028
Coast state notification	UC				0,00028		0,00028
Port arrival notification	UC				0,00028		0,00028

7.12 Future e-navigation services – Operational reporting

The types of services and transmission frequencies are shown below. Most messages are sent once a day except port services which are at 10 messages per day.

Table 32 – Traffic details for additional operational report data

Service	Mode	Hz in OS	Hz out OS	Hz in Co	Hz out Co	Hz in PA	Hz out PA
Commercial port services	UC			0,00012	0,00012	0,00012	0,00012
Navigational data update (ENC)	UC	0,00001		0,00001		0,00001	
Operating manuals, documents	UC	0,00001		0,00001		0,00001	
External maintenance and service	UC	0,00001	0,00001	0,00001	0,00001	0,00001	0,00001
Telemedicine	UC	0,00001	0,00001	0,00001	0,00001	0,00001	0,00001

7.13 Future e-navigation services – Crew infotainment

This is equivalent to the non e-Navigation variant except that message sizes have been increased to 10 MByte per day and crew.