The role of digital communication technology in e-Navigation

AUTHOR(S)
Ørnulf Jan Rødseth, Beate Kvamstad

CLIENT(S)
Internal

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 for ship to shore digital communication technology to realise the concept of e-Navigation. The report will also analyse the communication requirements and give an overview of some available and near future communication technologies. 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 3. A list of abbreviations is on page 7.

This work has been in part paid for by the European Commission and the Norwegian Research Council through the research projects Efforts (EU Project number FP6-031486), Flagship (EU project number TIP5-CT-2006-031406) and MarCom (NRC Project number 182678/I40).

\(^{1}\)IMO – International Maritime Organization

\(^{2}\)IALA – International Association of Marine Aids to Navigation and Lighthouse Authorities

KEYWORDS

<table>
<thead>
<tr>
<th>GROUP 1</th>
<th>ENGLISH</th>
<th>NORWEGIAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine technology</td>
<td>Marinteknikk</td>
<td></td>
</tr>
<tr>
<td>Communication technology</td>
<td>Kommunikasjonsteknologi</td>
<td></td>
</tr>
<tr>
<td>e-Navigation</td>
<td>e-Navigasjon</td>
<td></td>
</tr>
<tr>
<td>Radio technology</td>
<td>Radioteknologi</td>
<td></td>
</tr>
</tbody>
</table>
Disclaimer

The content of the publication herein is the sole responsibility of MARINTEK and it does not necessarily represent the views expressed by Norges Forskningsråd, the European Commission or their services. Neither do other participants in Flagship, Efforts or MarCom necessarily endorse any or all parts of this report.

While the information contained in the documents is believed to be accurate, the authors make no warranty of any kind with regard to this material including, but not limited to the implied warranties of merchantability and fitness for a particular purpose.

Neither the Flagship, Efforts or MarCom consortia nor any of its members, their officers, employees or agents shall be responsible or liable in negligence or otherwise howsoever in respect of any inaccuracy or omission herein.

Without derogating from the generality of the foregoing neither the Flagship, Efforts or MarCom consortia nor any of its members, their officers, employees or agents shall be liable for any direct or indirect or consequential loss or damage caused by or arising from any information advice or inaccuracy or omission herein.

Copyright © 2008-2009 Norsk Marinteknisk Forskningsinstitutt AS

The material contained in this document is protected by Norwegian copyright law. The material is scheduled to be used in forthcoming publications and the authors kindly ask that no parts of the document is generally published or broadcast without prior consent from MARINTEK. It is, however, acceptable to redistribute the document in verbatim form to individuals or groups that may have an interest in the issues discussed.

Acknowledgements

The content of this document is the result of work performed in the following projects:

- 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.

- 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.

- MarCom (Norwegian Research Council 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.
EXECUTIVE SUMMARY AND CONCLUSIONS

This report contains a fairly comprehensive overview of possible e-Navigation services. It characterises these services by message frequency and size, for different traffic scenarios (open sea, coast, and port). This is done with the presumption that limited bandwidth is available and that only “necessary” communication needs to be included. Thus, live video and similar high bandwidth demands are not included (see section 2.5 for more details).

The services are grouped into seven categories and the communication requirements for each service and group is estimated (Chapter 4). These groups is then put into six data carrier classes and traffic demands in each carrier class are estimated (Chapter 5). Some conclusions that can be drawn from this are:

1. AIS capacity is fairly close to maximum utilization, at least in congested waters, and should be reserved for real-time navigation data. There are limited possibilities to add more data to this carrier, unless new frequencies are added.
2. Purely navigational related services (excluding VTS image and ENC updates) could in principle be serviced by adding four to five channels for AIS type transmissions (about 30 kbps). However, this could also be done by two standard digital VHF channels.
3. Capacity demands are very much higher near coast and in port than at open sea. Thus, a shore based communication infrastructure can be used to cover coast and port approaches and by that complement satellite systems which in any case are necessary at open sea.
4. A total cumulative bandwidth of around 200 kbps should be sufficient to cover all relevant e-Navigation services, even in very busy ports. If VTS image and ENC updates are kept out, it should be sufficient with 100 kbps even when some crew infotainment services are included.

The report also looks at some possible technologies for carrying e-Navigation data (Chapter 6) and some factors that can determine what kind of communication system is most appropriate for future e-Navigation services (Chapter 7). Some possible conclusions from this are:

1. It seems likely that a combined satellite and terrestrial system may give best trade-off between benefits and drawbacks.
2. A terrestrial infrastructure may provide low cost solutions for the coastal fleet, which may be an important argument for developing nations.
3. Special systems are required to cover the Polar Regions beyond what GEO satellites reach. LEO or HEO satellites systems may be most appropriate.

This report argues for the use of terrestrial systems for implementing some of the e-Navigation services. If so, the system should be standardised internationally. Some possibilities are identified in the report:

1. Digital VHF seems to have enough bandwidth for “normal” bandwidth e-Navigation services, it has very good range and it uses frequencies that are already allocated to maritime mobile services.
2. WiMax on 450 or 790 MHz is attractive as it gives very good bandwidth and good 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. Other WiMax frequencies based on a private-public partnership could also be used. This could be used in a mesh structure (ship to ship forwarding) to extend range.

Some additional recommendations that were included in Chapter 8 are:

1. A new e-Navigation carrier should include mechanisms for authentication of sender, preferably based on the MMSI.
2. It may be useful to consider the support of self-organising or mobile base-station mechanisms in a new terrestrial carrier, to allow use in a local region also at high sea.
# TABLE OF CONTENTS

1. **Introduction** ........................................................................................................................... 9  
   1.1 Scope ........................................................................................................................... 9  
   1.2 Structure of document ...................................................................................................... 9  
   1.3 Revision history ................................................................................................................ 9  

2. **Background** ......................................................................................................................... 10  
   2.1 A short history of e-Navigation and the current definition ............................................ 10  
   2.2 e-Navigation and ship-shore communication ................................................................ 11  
   2.3 e-Navigation, e-Maritime and e-Freight: Communication types ................................... 12  
   2.4 A brief history of maritime radio ................................................................................... 13  
   2.5 Types of maritime communication carriers ................................................................... 14  

3. **Methods** ............................................................................................................................... 15  
   3.1 Types of communication ................................................................................................ 15  
   3.2 Carrier classes ................................................................................................................ 15  
   3.3 Communication demands estimates ............................................................................... 17  
   3.4 Principles for calculating overall bandwidth demands................................................... 18  

4. **Communication services** .................................................................................................... 21  
   4.1 Existing communication services ................................................................................... 22  
      4.1.1 Emergency management ................................................................................. 22  
      4.1.2 Position and safety reporting ........................................................................... 22  
      4.1.3 Additional navigational information ............................................................... 24  
      4.1.4 Mandatory ship reporting ................................................................................ 24  
      4.1.5 Operational reporting ...................................................................................... 25  
      4.1.6 Cargo and passengers ...................................................................................... 26  
      4.1.7 Crew infotainment ........................................................................................... 27  
   4.2 Emerging e-Navigation services ....................................................................................... 27  
      4.2.1 Position and safety reporting ........................................................................... 27  
      4.2.2 Emergency management ............................................................................... 28  
      4.2.3 Additional navigational information ............................................................... 29  
      4.2.4 Mandatory ship reporting ................................................................................ 31  
      4.2.5 Operational reporting ...................................................................................... 32  
      4.2.6 Crew infotainment ........................................................................................... 34  

5. **Aggregated communication requirements** ........................................................................... 35  
   5.1 Dedicated narrow band services..................................................................................... 35  
   5.2 AIS bandwidth requirements .......................................................................................... 36  
   5.3 General digital radio - today ........................................................................................... 36  
   5.4 General digital radio – future services ......................................................................... 37  
      5.4.1 Emergency services ......................................................................................... 37  
      5.4.2 Nautical services ............................................................................................... 38  
      5.4.3 Commercial services ...................................................................................... 39  
      5.4.4 Crew infotainment ........................................................................................... 39
6. Available and emerging ship communication technology

6.1 Satellite systems

6.2 New shore based systems

6.2.1 WiMax – IEEE 802.16

6.2.2 CDMA-450

6.2.3 Digital VHF

6.2.4 Suggested higher capacity digital VHF

6.3 Coverage in the Arctic region

6.4 Private or public services

6.4.1 Public services

6.4.2 Private services

6.4.3 Private-public partnerships

7. Possible solutions for e-Navigation carriers

7.1 Different possibilities in different areas

7.2 Coastal radio for long coast lines

7.3 Satellite or terrestrial systems for coastal communication

7.3.1 Sensitivity to ship movements and coastal coverage

7.3.2 High sea coverage

7.3.3 Real time performance

7.3.4 Cost for coastal fleet

7.3.5 Cost for high sea fleet

7.3.6 Cost of infrastructure

7.3.7 Coastal state control

7.3.8 Safety of Navigation

7.3.9 Security of infrastructure

7.3.10 Benefits for developing nations

7.3.11 Load balancing coast/high sea

8. Conclusions and recommendations

8.1 AIS bandwidth is fully utilized

8.2 Arguments for use of terrestrial carriers for e-Navigation

8.3 Standards are required

8.4 Benefits of VHF as carrier

8.5 Support for emergency management and general coordination at high sea

8.6 Authentication should be included

9. References
**LIST OF ABBREVIATIONS**

AIS – Automatic Identification System (VHF radio based ship position transponder)

AMVER – Automated Mutual Assistance Vessel Rescue System ([www.amver.org](http://www.amver.org))

AtoN – Aids to Navigation (traditionally buoys, marks etc., but in later days also electronic signs).

BNWAS – Bridge navigational watch alarm system

bps – Bits per second

EMC – Electro-Magnetic Compatibility

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”.

COSPAS/SARSAT – System for detecting EPIRB transmissions

DSC – Digital Selective Calling

DVB-RCS – Digital Video Broadcast, Return Channel via Satellite

ECDIS – Electronic Chart Display and Information System, alternative to paper charts

EGNOS – European Geostationary Navigation Overlay Service

ENC – Electronic Navigational Chart (“unofficial” ECDIS)

IALA – International Association of Aids to Navigation and Lighthouse Authorities

IMO – International Maritime Organization

ISM – Instrumentation, Scientific and Medical (Frequency bands)

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)

IMSO – International Maritime Satellite Organization

IRNSS – India Regional Navigation Satellite System

kbps – Kilobits per second

kByte – Kilo byte (1024 byte)

LRIT – Long Range Identification and Tracking (satellite based, four daily reports from ship)

MAN – Metropolitan Area Network

Mbps – Megabits per second

MByte – Mega byte (1 024 kByte)

MF – Medium Frequency (300 kHz to 3 MHz)

MIO – Maritime Information Object

MMSI – Maritime Mobile Service Identity

MRCC – Maritime Rescue Coordination Centre

MSC – IMO’s Maritime Safety Committee

MSI – Maritime Safety Information (NAVTEX type messages)

NAV – MSC Navigation subcommittee

NAVTEX – part of GMDSS; used to provide digital updates on information to mariners.
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 (Maritime traffic supervision and service centre)
UHF – Ultra High Frequency (300 MHz – 3 GHz)
1. Introduction

1.1 Scope
This report discusses e-Navigation and primarily its emerging requirements to digital communication bandwidth. E-Navigation is a critical development to ensure safe, secure and efficient maritime transport, particularly 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 also contains the results of a quantitative and qualitative analysis of possible communication requirements as well as gives an overview of some 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 brief overview of the methods employed to do the analysis.

Chapter four gives a description of existing and emerging maritime communication services and requirements.

Chapter five analyses the communication services with regards to bandwidth demands. This is grouped onto a number of possible data carrier types and accumulated demands on each carrier are estimated.

Chapter six gives an overview of the most relevant types of communication technology that is or will become available in the foreseeable future. This includes some discussions on general trade-offs between the carrier types.

Chapter seven discusses the benefits and drawbacks of terrestrial and satellite systems.

Chapter eight makes some conclusions from the report.

Chapter nine contains the list of references.

1.3 Revision history
V0.1 - 2008-03-07 – øjr: First draft
V1.0 - 2008-08-13 – øjr/bk: First draft release to ITU-IMO working group
V2.0 - 2009-03-05 – øjr: Draft revision before publication, updated some figures and ship counts.
V2.2 - 2009-03-26 – øjr/bk: Final version based on input from QA.
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, 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 and the COMSAR 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 Radio navigation 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;
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.

Table 1 – e-Navigation inputs

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Real-time (or real RT) update information</strong></td>
<td><strong>Safe navigation</strong></td>
</tr>
<tr>
<td>- AtoN (position, status, ...)</td>
<td>- Anti collision</td>
</tr>
<tr>
<td>- Maritime Safety Information (MSI)</td>
<td>- Anti grounding</td>
</tr>
<tr>
<td>- Radar</td>
<td>- Route planning and monitoring</td>
</tr>
<tr>
<td>- Position fixing systems</td>
<td>- Pilotage and berthing</td>
</tr>
<tr>
<td>- Ships’ sensors (heading, speed log ...)</td>
<td>- Keel and air-draft clearance</td>
</tr>
<tr>
<td>- Echo sounder</td>
<td>- Alert management</td>
</tr>
<tr>
<td>- Sonar (optional)</td>
<td>- Emergency management</td>
</tr>
<tr>
<td>- Inertial navigation system (optional)</td>
<td></td>
</tr>
<tr>
<td>- AIS data</td>
<td></td>
</tr>
<tr>
<td>- Meteorological</td>
<td></td>
</tr>
<tr>
<td>- Chart and publications updates</td>
<td></td>
</tr>
<tr>
<td><strong>Long-lead (reference) information</strong></td>
<td><strong>Efficiency and other benefits</strong></td>
</tr>
<tr>
<td>- Digital charts and publications</td>
<td>- Maritime reporting</td>
</tr>
<tr>
<td>- AtoN infrastructure and details</td>
<td>- Port state control, port operations</td>
</tr>
<tr>
<td>- Predicted met-ocean (season, tide ...)</td>
<td>- Potentially reduced insurance costs</td>
</tr>
<tr>
<td><strong>Organisational</strong></td>
<td>- Improved security</td>
</tr>
<tr>
<td>- Training and procedures</td>
<td>- SAR and pollution response</td>
</tr>
<tr>
<td>- QM procedures</td>
<td>- Infrastructure requirements analysis</td>
</tr>
<tr>
<td>- Data access and security</td>
<td>- Incident and risk analysis</td>
</tr>
<tr>
<td>- Mandatory documents (IMO, IHO, ...)</td>
<td>- Improved human efficiency</td>
</tr>
<tr>
<td>- International standards (IEC, ISO, ...)</td>
<td>- Improved ship efficiency</td>
</tr>
<tr>
<td>- Legal instruments</td>
<td>- Decision support mechanisms</td>
</tr>
</tbody>
</table>

Figure 1 – A descriptive model for e-Navigation [NNC07]

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.

Figure 2 – e-Relationships

E-Navigation is focused on safety, security and transport efficiency. This will not cover all aspects of the commercial and technical side of ship operations. Also, goods transport will normally involve more actors than just the ship and the port and also these aspects will to a large degree fall outside the scope of e-Navigation. To include the issues that fall outside 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.

With focus on radio communication, it is important to take this broader view and also to acknowledge the different nature of the communication types. Although e-Freight and e-Maritime will have great significance for international trade, one can assume that e-Navigation will get direct safety implications for ships and may require a more robust implementation than the other two.

2.4 A brief history of maritime radio

It is interesting to note that maritime applications have a significant share of frequencies in the bands up to and including HF (around 30 MHz), but almost no dedicated frequencies above that, the exceptions mainly being the VHF frequencies, 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 3 – Increase in number of mobile radio subscribers

Figure 3 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.

Thus, we are facing a problem when e-Navigation is going to be introduced. As will be shown later in this report, e-Navigation will require additional bandwidth for ship-shore communication, but there is currently no place where this bandwidth easily can be taken from. The commercial pressures from more general shore based traffic demands have a tendency of blocking additional frequencies for maritime safety data.
2.5 Types of maritime communication carriers

The main types of maritime communication systems in use today can be illustrated as in Figure 4:

1. Public narrow band (Green dashed) that is used to transmit, e.g., position fix information from satellites to ship, navigational warning messages to ships or short safety messages from ship to shore. The latter can be done via shore based radio or satellite.

2. AIS information (Blue dotted) exchanged between ships and shore. This is normally navigational status from ships, but can also contain other information related, e.g., to aids to navigation.

3. GMDSS voice communication (Red dashed/dotted) via VHF, satellite or also MF or HF.

4. Commercial voice and data channels (Magenta solid), usually over satellite, but which can also use GSM type networks or wireless data networks in or near ports.

Figure 4 – Marine communication types

When e-Navigation services are introduced, one can expect that many of the services will demand more digital transmission bandwidth than is in use or even available today. This will be discussed in the remaining part of this report.

One of the questions is what carrier to use to get this additional bandwidth. One possibility is AIS, but this has limited bandwidth (effectively about 6 kbps per channel) and will have capacity problem in high traffic areas. Another possibility is to use satellites, but this has a problem in that much of the communication can be looked at as public safety information which in principle should be made available for free. Thus, some shore authority may have to pay a substantial bill. Also, satellite receivers are relatively costly and may be too expensive for many coastal vessels.

Another question is how much bandwidth one will need. Digital bandwidth, or any other desirable resource for that matter, when made available for free or at a low cost, will always be used up to its capacity. Thus, demands will in reality only be limited by the capacity. To avoid this problem, this report has tried to identify a “minimum” requirement, representing good functionality without considering what additional, “nice to have” functionality one would want. The latter will typically include unlimited browsing of the Internet for crew or live video transmissions between ship and shore.
3. Methods

3.1 Types of communication

This paper proposes seven groups of communication services as illustrated in Figure 5. This grouping will be used to organise existing communication services and to function as a basis for proposing future e-Navigation related services.

![Figure 5 – Communication types](image)

These groups are defined as follows:

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

3.2 Carrier classes

With regards to communication carrier, the services described in the previous sub-section can be mapped onto three main "classes" of carriers. The mapping is illustrated in the figure below.
The carrier groups are briefly described below. Note that the "General digital radio" carrier group is divided into “Emergency”, "Nautical", “Crew” and "Other" carrier sub-groups, where Emergency and Nautical represents the services that are most relevant to e-Navigation. It is also in this sub-group we expect to see the highest demands on a new digital information carrier.

- **Dedicated narrow band**: These are services that are operating over a dedicated carrier and which typically use little bandwidth. The services included in this group are listed in Table 17 in the next main section.

- **AIS based**: The VHF based AIS system uses transponders onboard ships and in some cases base stations on land to send and receive 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.

- **General digital radio**: This is a class of carrier that may be public or private. Today it is private and it is typically Inmarsat or other VSAT systems that are used. Also some shore based systems, typically based on GSM is also commonly used and some ports offer WiMax or WiFi services to visiting ships. This type of carrier is divided into three sub-groups as listed below.
  
  - **Emergency**: This is communication between ships that are involved in handling an emergency at sea. If a general purpose digital radio system is fitted for use near shore, one can in principle assume that this system can also be used at sea to handle coordination between ships and other assets.
  
  - **Nautical**: This is safety or operational information that should be carried over a public data link.
  
  - **Crew**: Information exchanged between crew and people or organisations on shore or on other ships. May include infotainment, training or communication with family. This is most likely a commercial carrier.
Commercial: This is communication other than the classes above. Should normally be sent over private carriers. May typically be information exchanged as part of commercial processes.

Note that the digital radio communication carriers mostly form cells around base stations ashore. However, for the emergency carrier, one can assume that a group of ships at sea can form their own communication cell for use during critical operations.

3.3 Communication demands estimates

All communication services are listed in Chapter 4. Each service is allocated to one of the groups discussed in section 3.1 and characterised by a number of attributes that are listed in the below table.

Table 1 – Fixed parameters used in analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit rate (bps)</td>
<td>Capacity of channel, in bits per second</td>
</tr>
<tr>
<td>Message size (Bytes)</td>
<td>Typical mean size of message, weighted if relevant for differences in incoming and outgoing message sizes.</td>
</tr>
<tr>
<td>Mode (MD)</td>
<td>Specifies if service is unicast (UC) or broadcast (BC). This applies only to messages sent from shore to ship as it is assumed that the ship only sends one message (broadcast or unicast) at a time, independent of how many ships is in the radio cell.</td>
</tr>
<tr>
<td>Service (SV)</td>
<td>Specifies a commercial (CO), public (PU) or special service (SP). SP means that special consideration has been taken in load calculations, e.g., because the service is used in open sea only. PU means that the service is included in those that are relevant for a dedicated public service carrier.</td>
</tr>
<tr>
<td>Dedicated carrier (DD.)</td>
<td>Dedicated carrier (Y) or not (N). Applicable, e.g., to GPS and AIS that is bound to one specific carrier.</td>
</tr>
<tr>
<td>mpi/mpdo OS</td>
<td>Estimates in or output message frequency (message per day) in open sea scenario. Input is traffic to ship.</td>
</tr>
<tr>
<td>mpi/mpdo Co</td>
<td>Estimates in or output message frequency (message per day) in coastal scenario. Input is traffic to ship.</td>
</tr>
<tr>
<td>mpi/mpdo PA</td>
<td>Estimates in or output message frequency (message per day) in coastal scenario. Input is traffic to ship.</td>
</tr>
</tbody>
</table>

For frequencies, these are given in messages per day. Some high frequency updates, e.g., AIS AtoN will be reported as 4320 000, which is equivalent to five messages per second. Some other commonly used frequencies are listed below:

- 43 200 One message each two seconds
- 17 280 One message each five seconds
- 14 400 Ten messages per minute
- 144 One message each ten minutes
3.4 Principles for calculating overall bandwidth demands

The analysis is focused on a terrestrial radio service where one base station serves a number of ships within range of the base stations, i.e., one “radio cell”. Thus, the total bandwidth demand is the mean bandwidth demand for all ships within the cell. This is not completely appropriate for satellite services as they use a mix of narrow (spot) and wide beams to implement their services.

To determine an estimate for the communication bandwidth demand, three different scenarios have been defined:

- **Open sea**: In this scenario there are relatively few ships in the vicinity of each other. The ships are sending operational messages as well as messages related to crew, cargo and passenger requirements.

- **Coastal**: More ships are around. The ships are, in addition to the previous exchanges, also sending messages to coastal and port state authorities and in general preparing for port call.

- **Port approach**: As previous, but even more ships are contesting for bandwidth. There are also more messages being sent related to the coordination of the imminent port call.

Each scenario implies a different number of ships contending for bandwidth as well as different usage patterns for the services. Regarding the number of ships, one should note that the article only discusses ocean going ships. If fishing vessels, ferries and other local traffic is included, the figures may have to be increased with a factor between 2 and 3 [ISL07]. This is to some degree catered for in the high estimates below.

The numbers in Table 2 refer to an estimated maximum number of ships \(N_a\) that are within a radio cell at the same time, i.e., the number of ships that contend for bandwidth. An upper (High) and lower (Low) estimate for the number of ships are listed for each scenario. This allow for inter- or extrapolation to any other ship number as will be discussed later.

<table>
<thead>
<tr>
<th>Code</th>
<th>Low (N_a)</th>
<th>High (N_a)</th>
<th>Description</th>
<th>Usage pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>10</td>
<td>20</td>
<td>Open sea</td>
<td>Mostly ship operational messaging and infotainment</td>
</tr>
<tr>
<td>Co</td>
<td>100</td>
<td>200</td>
<td>Coastal area</td>
<td>Preparation for port calls, in addition to Open sea</td>
</tr>
<tr>
<td>PA</td>
<td>250</td>
<td>500</td>
<td>Port approach</td>
<td>Logistics for port calls, in addition to Open sea</td>
</tr>
</tbody>
</table>

Open sea figures depend heavily on where on the globe one looks, from close to zero ships per year to densities as in the coastal areas. The stated numbers are “best guess”. However, bandwidth demands in these areas are not very high and are most likely not critical for dimensioning a future communication infrastructure in any case.

The figures are probably on the high side for coastal traffic. The Strait of Malacca has reportedly around 150 ships passing each day [USDoE] while the Dover strait has 400 ships passing as well as 100 ferry crossings each day [MAIB07]. Given a typical ship speed of 10 to 15 knots in these
areas, 100 to 200 ships within a radio cell is on the high side, although local traffic will disturb this picture.

The port figures are based on access statistics for a collection of ports as shown in Table II. These numbers are somewhat uncertain as the classification of ships is different between the referenced sources. However, the figures of respectively 250 and 500 ships per day seem to be on the conservative high side, even though many ships stay for several days. Local traffic will also influence these figures. All figures in the table are from 2006.

<table>
<thead>
<tr>
<th>Port</th>
<th>Calls per year</th>
<th>Calls per day</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>39 020</td>
<td>110</td>
<td>[ISL07]</td>
</tr>
<tr>
<td>Singapore</td>
<td>55 577</td>
<td>160</td>
<td>[USDoE]</td>
</tr>
<tr>
<td>Hamburg</td>
<td>11 942</td>
<td>35</td>
<td>[ISL07]</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>30 781</td>
<td>90</td>
<td>[ISL07]</td>
</tr>
</tbody>
</table>

For the service utilization presented in the main chapter of the report (BW OS, BW Co, BW PA), the message frequencies have been converted to utilization through the following formula:

$$U = \begin{cases} 
(f_{\text{inp}} + f_{\text{out}}) \times N_a \times \delta b & t = \text{SP} \\
(f_{\text{inp}} + f_{\text{out}}) \times N_a \times \delta b & t \neq \text{SP} \land m = \text{UC} \\
(f_{\text{inp}} + f_{\text{out}}) \times N_a \times \delta b & t \neq \text{SP} \land m = \text{BC} \\
(f_{\text{inp}} + f_{\text{out}}) \times \delta b & t = \text{SP} 
\end{cases}$$

(1)

The symbols in the formula is described in the below table.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_a)</td>
<td>Number of ships</td>
<td>Ships in the area, according to scenario (s) as defined in Table I</td>
</tr>
<tr>
<td>(R)</td>
<td>Bit rate (bps)</td>
<td>Capacity of channel, in bits per second</td>
</tr>
<tr>
<td>(N_m)</td>
<td>Message size (Bytes)</td>
<td>Typical mean size of message, weighted if relevant for differences in incoming and outgoing messages</td>
</tr>
<tr>
<td>(f_{\text{inp}})</td>
<td>Hz in</td>
<td>Estimates ship's incoming message frequency in each scenario (s)</td>
</tr>
<tr>
<td>(f_{\text{out}})</td>
<td>Hz out</td>
<td>Estimates ship's outgoing message frequency in each scenario (s)</td>
</tr>
<tr>
<td>(m)</td>
<td>Mode</td>
<td>Specifies if service is sent to the ship as unicast (UC) or broadcast (BC)</td>
</tr>
<tr>
<td>(t)</td>
<td>Type</td>
<td>Specifies a public (PU), Commercial (CO) or special purpose (SP) service</td>
</tr>
<tr>
<td>(c)</td>
<td>Carrier</td>
<td>Carrier class as defined in section II.B, D – Dedicated, A – AIS, N – Nautical, C – Crew, O – Other.</td>
</tr>
<tr>
<td>(U)</td>
<td>Utilization</td>
<td>Percentage total utilization in an area, as defined in Table 2</td>
</tr>
</tbody>
</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.
4. Communication services

This chapter gives an overview of the communication services that have been considered as candidates in an e-Navigation scenario. This includes existing services (first sub-section) as well as emerging and possible services (second sub-section). The description is based on the grouping of services proposed in section 3.1.

![Figure 7 – Existing and new communication services](image)

The left hand side of Figure 7 illustrates existing services groups according to the description in section 3.1. The right hand side lists the service groups that are explained under the title “emerging services”. One can note that two service groups are left out of the latter.

For position and safety reporting, this is because this service group is looked at as fairly mature. 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\(^1\), new position augmentation systems or satellite based AIS receivers. Currently we do not see that these services will put any great demand on general purpose digital data channels as most or all of the services will use dedicated carriers. Thus, from the point of view of this report, they will most likely not contribute to the selection of specific data carriers for e-Navigation.

For the cargo and passenger group, the reason for leaving it out is that services in this group will be driven almost exclusively by commercial demands and available bandwidth. Thus, the group can be expected to have a low impact on general e-Navigation requirements and possibilities. Although this group probably will remain relatively unaffected by the introduction of e-Navigation, communication demands in this area can in any case be expected to grow and it may be a factor in covering the costs of new data carriers.

For the other groups, the transition is either labelled as “new” (Green arrow) or “add” (Blue arrow). This indicates if the new services in general have to be looked at as new and different (new) or if they are mainly more of the same as we have today (add). This will be further elaborated on in section 4.2.

---

\(^1\) Proposed European GNSS system
4.1 Existing communication services

This section goes through existing ship communication services that are commonly implemented over a digital carrier. We have not included services that are only performed over voice channels. The bit rates quoted are the bit rates normally employed, although this may vary. Note in particular that the bit rates for the AIS carrier is set to 19.2 kbps which corresponds to two independent AIS channels. Usually, AIS messages are sent on both channels which will reduce the available bandwidth to 9.6 kbps. Bit rates are not corrected for loss of capacity due to error correction or other protocol features. Thus, the effective bit rate, e.g., for AIS, is about 6 kbps per channel.

4.1.1 Emergency management

Emergency management has always been one of the focus areas in SOLAS. To a large degree it is based on continuously listening in on the safety voice channels to give rapid help, but there are also some digital services in this area. They are briefly described below.

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpi OS</th>
<th>mpi OS</th>
<th>mpi Co</th>
<th>mpi Co</th>
<th>mpi PA</th>
<th>mpi PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSC (via MF, HF or VHF)</td>
<td>1200</td>
<td>32</td>
<td>SP</td>
<td>Y</td>
<td>Y</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPIRB (406 MHz COSPAR SARSAT)</td>
<td>400</td>
<td>8</td>
<td>SP</td>
<td>Y</td>
<td>N</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSAS (Inmarsat)</td>
<td>128</td>
<td>8</td>
<td>SP</td>
<td>N</td>
<td>N</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td>1/100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

EPIRB – Emergency Position Indicator Radio Beacon can be implemented on VHF (DSC – as above) 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. This may, e.g., be implemented over Inmarsat.

As this type of communication mainly is in use during emergencies, they will obviously not put a great cumulative demand on the communication carrier. A nominal frequency of one message per 100 days has been used in the table. Note also that the service has been classified as “SP” to indicate that it will only apply to one single ship within the radio coverage area.

4.1.2 Position and safety reporting

Digital position and safety reporting is a relatively new group of services although radio based position systems are older. The group includes basic services related to position fixing by ships and safety and position reporting from ships. It is a fairly demanding group of services in relationship to the bandwidth they are allocated. In particular, AIS can be expected to be utilized quite heavily in congested waters. However, the services are allocated to dedicated bandwidth and this bandwidth is in general adapted to the service demands.
Table 6 – Position and safety reporting requirements

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpi OS</th>
<th>mpi Co</th>
<th>mpi OS</th>
<th>mpi Co</th>
<th>mpi OS</th>
<th>mpi Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS (GPS, Glonass, Galileo)</td>
<td>23</td>
<td>82</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>43200</td>
<td>43200</td>
<td>43200</td>
<td>43200</td>
<td>43200</td>
<td>43200</td>
</tr>
<tr>
<td>AIS position report (msg. 1, 2, 3)</td>
<td>19200</td>
<td>32</td>
<td>UC</td>
<td>PU</td>
<td>Y</td>
<td>7200</td>
<td>14400</td>
<td>14400</td>
<td>14400</td>
<td>14400</td>
<td>14400</td>
</tr>
<tr>
<td>LRIT position report (Inmarsat)</td>
<td>128</td>
<td>8</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>DSC (via MF, HF or VHF)</td>
<td>1200</td>
<td>32</td>
<td>UC</td>
<td>PU</td>
<td>Y</td>
<td>24</td>
<td>24</td>
<td>72</td>
<td>72</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>AMVER (position report)</td>
<td>128</td>
<td>8</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**GNSS** – Global Navigation Satellite System where GPS (Global Positioning System) arguably is the most known component. It transmits certain data that can be transformed into time and position information. GNSS also includes GPS and GLONASS as well as Galileo (Europe), COMPASS (China), IRNSS (India) or other systems when these become operational. The high bandwidth demand on these systems indicates that the dedicated carrier is utilized as far as possible.

**AIS** – Automatic Identification System is a VHF based position (and other information) reporting system that is used for both navigational and security purposes. It is most often used to report ships position, heading and speed to aid other ships in navigating safely. 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. The mean transmission frequency has been set to between five and ten per minute. This should be acceptable as the actual message frequency will vary with ship speed and manoeuvring up to twice a second.

**LRIT** – Long Range Identification and Tracking is similar to AIS, but intended for distances up to 1000 nautical miles from shore. It contains far less information than the AIS message and has a relatively low update rate (four times a day in this table). It is normally sent via Inmarsat.

**DSC** – Digital Selective Call is a digital communication mechanism on MF, HF and VHF. Most commonly used on VHF Channel 70 it is used to, among other things, to set up radio voice calls. In the estimates we have used between one and five calls per hour and per ship. More calls are assumed during port approach where coordination with the port, tugs and pilots may be required.

**AMVER**[^2] is not a mandatory service for most ships, but is included here as it is more related to these than to purely operational messaging. AMVER collects ship position reports to more rapidly find ships that can help other ships that are in distress. AMVER and similar services require a short report from the ship each 4 to 6 hours. The service will most commonly use Inmarsat.

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

Note also that the proposed e-Loran [eLoran] service has some digital capability that can be used, e.g., for differential corrections. The capability is on the same order as GNSS signals and is not included here.

[^2]: Automated Mutual Assistance Vessel Rescue System, [www.amver.com](http://www.amver.com)
4.1.3 Additional navigational information

Today this group of services include various short message data services to the ship. This includes data related to position fixes and navigational safety that enhances information from the more purely safety and position fix related services. With this definition, one can easily guess that this is the group where one can expect many of the new e-Navigation services to emerge. The following paragraphs give a brief description of some of the current services in this group.

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpi OS</th>
<th>mpi do OS</th>
<th>mpi Co</th>
<th>mpi PA</th>
<th>mpi do PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential GNSS (RTCM)</td>
<td>200</td>
<td>32</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>17280</td>
<td>17280</td>
<td>17280</td>
<td>17280</td>
<td></td>
</tr>
<tr>
<td>AIS (other messages, AtoN)</td>
<td>19200</td>
<td>125</td>
<td>BC</td>
<td>PU</td>
<td>Y</td>
<td>432000</td>
<td>432000</td>
<td>432000</td>
<td>432000</td>
<td></td>
</tr>
<tr>
<td>NAVTEX (MSI)</td>
<td>300</td>
<td>125</td>
<td>BC</td>
<td>PU</td>
<td>Y</td>
<td>144</td>
<td>144</td>
<td>144</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>SafetyNET (MSI over Inmarsat)</td>
<td>1200</td>
<td>125</td>
<td>BC</td>
<td>PU</td>
<td>Y</td>
<td>144</td>
<td>144</td>
<td>144</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>Weather fax</td>
<td>2500</td>
<td>17000</td>
<td>BC</td>
<td>PU</td>
<td>Y</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Differential GNSS corrections are received as data packets [RTCM 194] from various suppliers over radio, satellite or even Internet. This can also include EGNOS corrections. Communication bandwidth is dependent on the ship’s accuracy requirements, but even for high accuracy real time corrections, one will normally require relatively low bandwidths.

Aids to Navigation over AIS can send electronic information about hazards to navigation or more 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.

NAVTEX is a MF or 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. MSI is a common abbreviation for Maritime Safety Information, which can include both NAVTEX and SafetyNet.

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 more general 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 charts and other navigational information updates.

4.1.4 Mandatory ship reporting

Mandatory ship reporting is 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\(^3\), but relatively recently also ISPS\(^4\) data, waste management data and any other information have been included in the information required by international, regional or national legislation.

**Table 8 – Mandatory ship reporting requirements**

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpdi OS</th>
<th>mpdo OS</th>
<th>mpdi Co</th>
<th>mpdo Co</th>
<th>mpdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship reporting</td>
<td>9600</td>
<td>1000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Coast state notification</td>
<td>9600</td>
<td>1000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port arrival notification</td>
<td>9600</td>
<td>5000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td></td>
<td>20</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This communication is often in digital form, although it can be sent as fax, e-mail or even voice. The groups of reporting covered in this report are briefly described below.

**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. These messages are often given as voice messages 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 20 to 30 messages are sent in conjunction with a typical international port call. See [MarNIS 2004] for a more detailed description of this process. Note that many of these messages can be sent by the ship agent or other shore representatives for the ship.

4.1.5 **Operational reporting**

Operational reporting is communication between the ship and the owner, charterer, port, terminal, 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 – Operational communication requirements**

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpdi OS</th>
<th>mpdo OS</th>
<th>mpdi Co</th>
<th>mpdo Co</th>
<th>mpdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyage orders and reports</td>
<td>9600</td>
<td>2000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Commercial port call messages</td>
<td>9600</td>
<td>2000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Operational reports</td>
<td>9600</td>
<td>5000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather forecast</td>
<td>9600</td>
<td>5000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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. Typical frequency is one to two a day. The size has been set to 2 kByte which corresponds to what we have seen in current systems.

**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

---

\(^3\) FAL Form - IMO Facilitation Committee's proposed standard formats for ship clearance reports

\(^4\) ISPS - International Code on Ship and Port Facility Security

© 2008-2009 MARINTEK
service providers. Some of these messages may be quite large (e.g., bay plan messages for loading or discharge), but a mean size of 2 kByte has been used here to also cater for short arrival notifications etc. A frequency of three to five a day has been used, with no messages sent at open sea.

**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. Three messages in and out with a mean size of 3 kByte have been used in the estimates. This corresponds to common messages used for engine performance and, e.g., messages related to onboard stocks or safety management.

**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). One 5 kByte message a day has been used in the estimates here. This would correspond to updated textual information on suggested routes or expected weather, but does not cover more detailed forecast data. The latter is included in the e-Navigation section.

### 4.1.6 Cargo and passengers

Some types of cargo, including passengers, will require or request access to information channels for remote monitoring/control or for other purposes. 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.

**Table 10 – Passenger and cargo communication requirements**

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpi</th>
<th>mpi</th>
<th>mpi</th>
<th>mpi</th>
<th>mpi</th>
<th>mpi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo telemetry, online monitoring</td>
<td>64000</td>
<td>10000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Special ship, data gathering</td>
<td>1500000</td>
<td>100000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
</tr>
<tr>
<td>Passenger infotainment</td>
<td>1500000</td>
<td>100000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>86400</td>
<td>1440</td>
<td>86400</td>
<td>1440</td>
<td>86400</td>
<td>1440</td>
</tr>
<tr>
<td>Payments and inventory</td>
<td>64000</td>
<td>10000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
<td>86400</td>
</tr>
</tbody>
</table>

**Cargo telemetry:** 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 figures used here is 10 kByte each hour.

**Special ships:** Some ship, e.g., for seismic exploration, do data collection that needs to be transmitted to shore. Again, rates and amounts will vary. Here is used a rate of one hertz with mean message sizes of 100 kByte.

**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 as determined from the MarNIS project [MarNIS 2006a].

**Payments and inventory:** Smaller (and large) passenger ships will often have facilities for on-line payments from passengers and integrated inventory management. The figures used represent an estimate based on one transaction per second with a message size of 1 kByte.
4.1.7 Crew infotainment

Crew access to e-mail and Internet is necessary to recruit competent crew today and in the future. This is typically a service that will use all available bandwidth, at least when it is offered for free. However, this analysis has looked at what one can call minimum requirements, e.g., a certain kilobytes per crew per day.

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpdi OS</th>
<th>mpdo OS</th>
<th>mpdi Co</th>
<th>mpdo Co</th>
<th>mpdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew communication to family/home</td>
<td>9600</td>
<td>50000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Crew training</td>
<td>9600</td>
<td>50000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

In the analysis one has divided this type of communication into two:

Family/Home: General communication related to keeping in touch with life at shore. This could also include general Internet browsing where this is available. The figures used correspond to 20 messages of 50 kByte each day. This could be typical for a standard merchant ship.

Crew training: This is communication related to continuous training of crew as may be necessary to maintain certificates or as part of company policy. Figures used are two messages of 50 kByte per day (one tenth of private communication).

In general, ships will have limited communication capacity at high seas, at best in the range 64 to 128 kbps. Thus, it will also in the future be a hard limit on how much bandwidth will be available for these services. In this overview, we have indicated a bit rate of 9.6 kbps which corresponds to Inmarsat C.

4.2 Emerging e-Navigation services

This section lists possible new e-Navigation communication services or other emerging services related to e-Navigation. With a few exceptions, it does not include services implemented over dedicated carriers, such as AIS or position fix information. All bit rates are set to 100 kbps to facilitate simpler comparison.

4.2.1 Position and safety reporting

The services described in the following sections are not included in the later bandwidth analysis, but they are included here as they may get a significant impact on future shipping.

AIS receivers on satellite: This is a service that is already being tested by some countries, e.g., USA and Norway. The idea is to pick up AIS signals from low orbit satellites and relay these to land stations for tracking ships out of normal AIS range.

Safety status messages from ship: One new service that has been proposed is an autonomous transmission of a ship’s safety status with regards to its overall capability. Thus, any anomaly onboard like engine problems, a Bridge Navigational Watch Alarm, excessive cross-track errors or missed waypoints could automatically be sent to the nearest monitoring station, e.g., a SAR station or a VTS centre. This service would need a relatively low update rate, e.g., once a minute and could be accommodated over AIS or any other carrier. The idea is that such a system could significantly improve a monitoring station’s ability to get an early warning of potential problems.
Neither of the above services will impact new communication demands as they are very low bandwidth and/or implemented over existing services. Thus, they will not be considered in the discussions in the next section on communication bandwidth demands.

4.2.2 Emergency management

Recent EU projects, e.g., DSS_DC\(^5\) and Flagship\(^6\) have highlighted the potential benefits of using digital communication during emergencies. Digital data links can more accurately transfer information about the actual state and save the emergency management team from much of the voice traffic that is currently necessary to coordinate an emergency.

There are at least two possible and complementary scenarios one can foresee for emergency management in an e-Navigation context. One scenario increases communication between the ship in distress and shore based organisations, in particular the owner’s emergency management team and the search and rescue (SAR) services. The other scenario increases communication between the ship in distress and other ships in the area.

The first scenario will use generally available communication links, e.g., Inmarsat or VSAT or possibly new shore based services. Independent of this happening at sea or near the coast, the communication demands will be limited to the ship in distress or possibly one or a few other ships. Thus, the bandwidth demand will only depend on the number of emergencies one can expect and will not scale with the number of ships in a particular area.

The second scenario is particularly interesting in a setting where a direct link radio system is used locally between ships in a distress area. This means that the system could be used at high sea if one or more ships were able to act as base stations or if the communication system was self-organizing as AIS is. Thus, if a shore based digital radio system was deployed for ship-shore communication during coastal transit; this system could also be used locally for more efficient emergency management. Note that also “integrated operations” could be implemented over such a link. This could include various forms of platform-ship interaction, tug-ship interaction or any operation that needs close coordination between parties.

The above discussion should show that emergency management may not be a critical driver for the technology used to implement an e-Navigation strategy. It is relatively rarely used and will not put a great cumulative demand on the carriers. It will also need various fall-back solutions that may be preferred in certain cases. However, emergency management and possibly integrated operations can make significant use of an infrastructure that it suited to its purposes. Thus, it is an interesting provider of requirements to the service.

Table 12 – Additional emergency management requirements

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpdi OS</th>
<th>mpdo OS</th>
<th>mpdi Co</th>
<th>mpdo Co</th>
<th>mpdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication to other ship</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
</tr>
<tr>
<td>Communication to SAR</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
</tr>
<tr>
<td>Communication to owner's office</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
<td>2880</td>
<td>43200</td>
</tr>
</tbody>
</table>

\(^5\) DSS_DC: Decision Support for Ships in degraded Condition
\(^6\) Flagship integrated project: see [www.flagship.be](http://www.flagship.be)
There are three types of communication considered in this report:

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.

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 on the order of 64 kbps.

The frequency estimates in this case is valid for the duration of the incident and not based on yearly demands. It is based on a status message each two seconds from the ship in distress and additionally updates from other ships each 30 seconds.

There are luckily few incidents with ships that require emergency coordination. Thus, the traffic demands from emergency management cannot directly be aggregated with other demands. Thus, the service type has been classified as “SP” – Special.

Note also that emergency management in open sea may use a carrier intended for coastal areas. In this case, it does not impact the overall capacity of the shore system. Further more, one may also implement prioritization in the communication system so that emergency management can get a certain share of available bandwidth. This means that in the rare cases where emergencies happen, one can still support it although overall mean capacity may be used fully in that area.

For these reasons, emergency management is discussed separately in the considerations of overall communication requirements.

### 4.2.3 Additional navigational information

This is perhaps the most obvious area for extending communication services into the e-Navigation domain. 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

This is also in line with the observations that have been documented in this report. The estimates on future service demands is listed in the table and briefly discussed below.
Table 13 – Additional navigation requirements

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mdi OS</th>
<th>mpdo OS</th>
<th>mdi Co</th>
<th>mpdo Co</th>
<th>mdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTS coordination</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIO</td>
<td>100000</td>
<td>10000</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>120</td>
<td>720</td>
<td>720</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPU - VTS image</td>
<td>100000</td>
<td>10000</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>8640</td>
<td>8640</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real time met-ocean</td>
<td>100000</td>
<td>10000</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tug/mooring coordination</td>
<td>100000</td>
<td>100000</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load/discharge coordination</td>
<td>100000</td>
<td>50000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port ENC updates</td>
<td>100000</td>
<td>1000000</td>
<td>BC</td>
<td>PU</td>
<td>N</td>
<td>480</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High accuracy berthing control</td>
<td>100000</td>
<td>50000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**VTS:** One area that is particularly mentioned in the IALA report is the VTS 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. In this estimate, this is looked at as relatively small messages related directly to recommendations to the ship. The estimate is ten messages per day to each ship in all zones. The PPU entry considers broadcast of general situation data (e.g., radar images) from VTS to ships in the area.

**MIO:** 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)

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. The traffic estimate is based on 30 broadcasts of 10 kByte messages each hour in coastal and port approach areas.

**PPU:** 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 unit7 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. In the estimates we have used one 100 kByte image broadcast 10 times per second.

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). The data traffic estimate is one 100 kByte image broadcast once an hour.

The EU-supported Efforts project8 is also investigating various new forms of navigational assistance for ships in port. Some of these have been included here. Note that tug/mooring assistance and load/discharge coordination is similar to emergency management in that it is intended to facilitate real-time coordination between ships and port assets. However, in this scenario, the data traffic has been modelled as one relatively big data block once per day per ship in the relevant areas. In real life this will be a relatively large set of smaller messages during the operation.

Tug/Mooring assistance: It may be useful to set up direct and real-time communication between mooring crew and/or tugs and the ship and use this to coordinate actions through electronic decision support systems. The system could, e.g., provide a display showing all actors status, position and intentions. This would facilitate on-line updates of each party's intentions and actions and may support more efficient and safer operation. The estimated data requirement is 100 kByte of data exchanges per day and ship.

Load/discharge coordination: This is the same function as the previous, but for load and discharge operations. This may be particularly useful for crane operations where ship's crew are required to assist. The estimated data requirement is 50 kByte of data exchanges per day and ship.

Port ENC updates: Many or most ports have more accurate electronic maps than the Hydrographic office. Ports update maps continuously, both for navigational safety and for operational purposes. It would in principle be useful if ships were supplied with these accurate ENC updates at port approach. Although this has certain regulatory and liability issues, it would arguably enhance maritime safety and efficiency. In this estimate we have used 20 messages of 1 MByte transmitted 20 times per hour.

High accuracy berthing control: There are systems available to give special monitoring and control data to the ship during berthing. This can be used to partly optimize the operation or to give decision support to the navigational officer. Data that may be transmitted are typically distances to bollards or reference positions, speed of movements etc. This can be used to make operations more efficient and it may also reduce damage to ship, quays and fenders as a result of fast movements. In the estimates we have used the same figures as for loading and discharge, i.e., a total of 50 kByte per ship per day.

4.2.4 Mandatory ship reporting
There are no new specific services defined in this group. However, the expectation is that message sizes and number 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

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mdi OS</th>
<th>mpdo OS</th>
<th>mdi Co</th>
<th>mpdo Co</th>
<th>mdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship reporting</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coast state notification</td>
<td>100000</td>
<td>5000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port arrival notification</td>
<td>100000</td>
<td>25000</td>
<td>UC</td>
<td>PU</td>
<td>N</td>
<td>20</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The frequency and size has been adjusted by increasing only the size with a factor five compared to existing services without changing frequencies. 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 and, thus, fall under the category additional navigation information. This will in any case be negligible with regards to overall data traffic.

4.2.5 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 between general onboard and on shore systems certainly creates possibilities in this area. Thus, operational reporting is also an area that is expected to increase significantly in an e-Navigation scenario.

Table 15 – Extended operational communication requirements

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mdi OS</th>
<th>mpdo OS</th>
<th>mdi Co</th>
<th>mpdo Co</th>
<th>mdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyage orders and reports</td>
<td>100000</td>
<td>10000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Commercial port call services</td>
<td>100000</td>
<td>10000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Navigational data update (ENC)</td>
<td>100000</td>
<td>10000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Operational reports</td>
<td>100000</td>
<td>15000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Operating manuals, documents</td>
<td>100000</td>
<td>10000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weather forecast</td>
<td>100000</td>
<td>10000</td>
<td>UC</td>
<td>CO</td>
<td>N</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Teledicine</td>
<td>100000</td>
<td>100000</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Voyage orders and reports as well as operational reports are the same as have been described in section 4.1.5. To cater for an increased need for information, the message sizes have been increased with a factor five. This should be read as increased frequency as well as increased data set size.

Advanced commercial port call services will soon be a reality in Singapore, where a WiMax network is being deployed for visiting ships. 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:

- 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.

8 Effective Operations in Port www.efforts-project.org
• 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.

To cater for these possibilities, the message size has been increased with a factor five compared to existing services discussed in section 4.1.5.

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. 100 kByte once a day has been used in the estimates. Note that this has been flagged as a unicast service as it is assumed that different ships will have different needs for chart updates.

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. 10 kByte once a day has been used in the estimates.

External maintenance and service: 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. The estimate has used 50 kByte per day. This will probably be divided into different size messages.

Advanced weather forecasts: Additional types of weather forecasts, e.g., ensemble forecasts [Zhua02], may also be a part of future e-Navigation services. To allow for increased functionality, e.g., in the form of more advanced and detailed information, message sizes have been increased by a factor 20 compared to existing services, so the total is now set to 100 kByte per day.

Telemedicine: Tele-medicine is also a part of shipping today, but usually with the help of voice communication. In the e-Navigation scenario, this has been included as a digital service. This may, e.g., include remote diagnostic equipment, video conferencing or other technology. However, this is normally a rare service to be called on and it will not demand much in terms of the aggregated bandwidth requirements. Thus, it has been flagged as a special purpose service not to be scaled with the number of ship and the demands has been set to 1 MByte per day. This will then be the estimated total demand within one radio coverage cell.
4.2.6 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.

Table 16 – Extended crew infotainment requirements

<table>
<thead>
<tr>
<th>Service</th>
<th>bps</th>
<th>Byte</th>
<th>MD</th>
<th>SV</th>
<th>DD</th>
<th>mpdi OS</th>
<th>mpdo OS</th>
<th>mpdi Co</th>
<th>mpdo Co</th>
<th>mpdi PA</th>
<th>mpdo PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew communication to family/home</td>
<td>100000</td>
<td>1E+07</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Crew training</td>
<td>100000</td>
<td>1E+07</td>
<td>UC</td>
<td>SP</td>
<td>N</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

This is equivalent to the non e-Navigation variant except that message sizes have been increased to 10 MByte per day and crew instead of 50 kByte as in the previous example. The frequencies have been kept at the previous level. Note that this amount of data goes both in to and out from the ship.

As was noted in section 2.5, communication demands will always fill or exceed availability. This can safely be assumed to be the case also for crew communication. With a typical VSAT data rate of 128 kbps, 20 MByte only corresponds to about 22 minutes of full capacity use per day.

However, with 20 crew on board and only a 64 kbps link, one has used almost 15 hours of the full capacity of the data link.

Note also that general Internet surfing is a highly asymmetrical operation with much more data being sent to the ship than from. Thus, other satellite technology such as DVB-RCS may be applicable here.
5. Aggregated communication requirements

This section lists the aggregated communication demands in four scenarios. The first is the demands over dedicated carriers, except AIS. This is mainly today’s communication requirements which are aggregated to give an idea of how much data bandwidth one is commonly using. The second scenario is AIS based communication which is also based on today’s requirements. The third is today’s general carrier communication and the last is the possible demands that e-Navigation may pose to a general data carrier. This last scenario is divided into each of the carrier classes listed in section 3.2. Note that all bit rates has been normalized to 100 kbps for the future carrier classes to facilitate comparison. The method for calculating communication demands is discussed in section 3.4.

5.1 Dedicated narrow band services

Table 17 lists the cumulative bandwidth demands for dedicated narrow band services in use today. These figures are for the low estimates of ships in an area. It is only the DSC type services that will be significantly afflicted by increasing the ship numbers as this is the only service with relatively high utilization of unicast type communication. DSC demands with high estimates will be twice the figures presented here, i.e., about 30%.

Note that DSC is listed twice (line 1 and 6). This is because DSC can be used both for emergency management and for regular connections of ship/ship or ship/shore calls. The zeros in the first three lines of the table show that the communication requirement is less than half a byte per day. This is representative for emergency management functions as emergencies are relatively rare and do not pose a significant communication demand for these services.

### Table 17 – Dedicated narrow band bandwidth requirements

<table>
<thead>
<tr>
<th>Emergency management</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSC (via MF, HF or VHF)</td>
<td>1200</td>
<td>32</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>Y</td>
</tr>
<tr>
<td>EPIRB (406 MHz COSPAS SARSAT)</td>
<td>400</td>
<td>8</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>Y</td>
</tr>
<tr>
<td>SSAS (Inmarsat)</td>
<td>128</td>
<td>8</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>0,00 %</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position and safety reporting</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS (GPS, Glonass, Galileo)</td>
<td>50</td>
<td>8</td>
<td>64,00 %</td>
<td>64,00 %</td>
<td>64,00 %</td>
<td>Y</td>
</tr>
<tr>
<td>LRIT position report (Inmarsat)</td>
<td>128</td>
<td>8</td>
<td>0,02 %</td>
<td>0,23 %</td>
<td>0,58 %</td>
<td>N</td>
</tr>
<tr>
<td>DSC (via MF, HF or VHF)</td>
<td>1200</td>
<td>32</td>
<td>0,12 %</td>
<td>3,56 %</td>
<td>14,81 %</td>
<td>Y</td>
</tr>
<tr>
<td>AMVER (position report)</td>
<td>128</td>
<td>8</td>
<td>0,02 %</td>
<td>0,23 %</td>
<td>0,58 %</td>
<td>N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional navigational information</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential GNSS (RTCM)</td>
<td>200</td>
<td>36</td>
<td>28,80 %</td>
<td>28,80 %</td>
<td>28,80 %</td>
<td>Y/N</td>
</tr>
<tr>
<td>NAVTEX (MSI)</td>
<td>300</td>
<td>128</td>
<td>0,57 %</td>
<td>0,57 %</td>
<td>0,57 %</td>
<td>Y</td>
</tr>
<tr>
<td>SafetyNET (MSI over Inmarsat)</td>
<td>1200</td>
<td>128</td>
<td>0,14 %</td>
<td>0,14 %</td>
<td>0,14 %</td>
<td>Y</td>
</tr>
<tr>
<td>Weather fax</td>
<td>2500</td>
<td>170000</td>
<td>6,30 %</td>
<td>6,30 %</td>
<td>6,30 %</td>
<td>Y</td>
</tr>
</tbody>
</table>

Although the group is called "dedicated narrow band", some of the services are implemented over general purpose satellite or VHF services, e.g., DSC and LRIT. However, as one can see, the load on the general purpose carriers by these services is close to negligible. The exception seems to be DSC which may amount to up to 15% (30% for high number of ships estimate) of available bandwidth. However, this is calculated from the available digital bandwidth on Channel 70 where DSC is implemented. This channel is reserved for DSC and the utilization is low in this context.
One can expect these services to be kept and probably somewhat expanded in an e-Navigation scenario. However, bandwidth requirements will still be fairly low and many carriers will still be dedicated. Thus, these services will not have a significant influence on selection of carrier for future e-Navigation services.

5.2 AIS bandwidth requirements

The AIS related services are summarised in the below table. The first table is for the low estimate of ships, the second for the high. The figures represent mean utilization of the capacity of the AIS system based on estimates in the previous section. Note that AIS contains mechanisms for bandwidth adaptation that will support a fairly high number of ships, but at reduced update rates. Thus, the utilization of 111% does not directly represent a problem.

<table>
<thead>
<tr>
<th>Position and safety reporting</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
<th>DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS position report (msg. 1, 2, 3)</td>
<td>19200</td>
<td>32</td>
<td>1,11 %</td>
<td>22,22 %</td>
<td>55,56 %</td>
<td>Y</td>
</tr>
<tr>
<td>AIS (other messages, AtoN)</td>
<td>19200</td>
<td>32</td>
<td>6,67 %</td>
<td>6,67 %</td>
<td></td>
<td>Y</td>
</tr>
</tbody>
</table>

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 the spare capacity of this carrier in these areas, would not be possible to standardize for general purpose international traffic. Thus, in the authors' opinion, AIS is less relevant for general purpose e-Navigation services beyond what it already supports.

5.3 General digital radio - today

Table 19 list today’s general radio services in all carrier classes. The ship number estimates used in this calculation are the low numbers. As one can see, except for special and passenger ship demands, the maximum utilization is low and well within the normal carriers’ capabilities.

If the bandwidth requirements are added together for the nautical carrier class, keeping commercial and crew communication out of the sum, the results for the low and high estimates of ships are as shown in Table 20.

Even with a bandwidth of 9.6 kbps there should be more than enough bandwidth available for all of today’s services.
Table 19 – Operational services bandwidth demands

<table>
<thead>
<tr>
<th>Mandatory ship reporting</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship reporting</td>
<td>9600</td>
<td>1000</td>
<td>0.19 %</td>
<td>0.48 %</td>
<td></td>
</tr>
<tr>
<td>Coast state notification</td>
<td>9600</td>
<td>1000</td>
<td>0.39 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port arrival notification</td>
<td>9600</td>
<td>5000</td>
<td>9.65 %</td>
<td>4.82 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational reporting</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyage orders and reports</td>
<td>9600</td>
<td>2000</td>
<td>0.06 %</td>
<td>0.58 %</td>
<td>1.45 %</td>
</tr>
<tr>
<td>Commercial port call messages</td>
<td>9600</td>
<td>2000</td>
<td>1.54 %</td>
<td>3.86 %</td>
<td></td>
</tr>
<tr>
<td>Operational reports</td>
<td>9600</td>
<td>3000</td>
<td>0.17 %</td>
<td>1.74 %</td>
<td>4.34 %</td>
</tr>
<tr>
<td>Weather forecast</td>
<td>9600</td>
<td>5000</td>
<td>0.05 %</td>
<td>0.48 %</td>
<td>1.21 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cargo and passengers</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo telemetry, online monitoring</td>
<td>64000</td>
<td>10000</td>
<td>0.03 %</td>
<td>0.03 %</td>
<td>0.03 %</td>
</tr>
<tr>
<td>Special ship, data gathering</td>
<td>1500000</td>
<td>100000</td>
<td>53.33 %</td>
<td>53.33 %</td>
<td>53.33 %</td>
</tr>
<tr>
<td>Passenger infotainment</td>
<td>1500000</td>
<td>100000</td>
<td>54.22 %</td>
<td>54.22 %</td>
<td>54.22 %</td>
</tr>
<tr>
<td>Payments and inventory</td>
<td>64000</td>
<td>1000</td>
<td>25.00 %</td>
<td>25.00 %</td>
<td>25.00 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crew infotainment</th>
<th>bps</th>
<th>Bytes</th>
<th>Tot BW</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew communication to family/home</td>
<td>9600</td>
<td>50000</td>
<td>1.93 %</td>
<td>1.93 %</td>
<td>1.93 %</td>
</tr>
<tr>
<td>Crew training</td>
<td>9600</td>
<td>5000</td>
<td>0.19 %</td>
<td>0.19 %</td>
<td>0.19 %</td>
</tr>
</tbody>
</table>

Table 20 – Aggregated nautical carrier class demands

<table>
<thead>
<tr>
<th>Carrier class</th>
<th>Bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nautical low</td>
<td>9600</td>
<td>0.28 %</td>
<td>14.56 %</td>
<td>16.16 %</td>
</tr>
<tr>
<td>Nautical high</td>
<td>9600</td>
<td>0.56 %</td>
<td>29.13 %</td>
<td>32.31 %</td>
</tr>
</tbody>
</table>

Note that crew communication is listed as a special purpose service (SP). This means that the requirements shown in Table 19 apply to one ship alone. Thus, it will not be possible to accommodate crew communication on a relatively narrow band communication link if it has to be shared between all ships in a radio cell.

5.4 General digital radio – future services

This section goes through the emerging communication requirements as described in section 4.2, aggregated into the carrier classes discussed in 3.2. All bit rates are normalized onto one carrier with a capacity set to 100 kbps. This is done to make comparisons easier.

5.4.1 Emergency services

Emergency services have been classified as special purpose (SP) to show that they do not apply to all ships in an area. Thus, the capacity demands indicated below will not depend on ship density or area.

Table 21 – Emergency services

<table>
<thead>
<tr>
<th>Emergency management</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication to other ship</td>
<td>100000</td>
<td>21 %</td>
<td>21 %</td>
<td>21 %</td>
</tr>
<tr>
<td>Communication to SAR</td>
<td>100000</td>
<td>21 %</td>
<td>21 %</td>
<td>21 %</td>
</tr>
<tr>
<td>Communication to owner's office</td>
<td>100000</td>
<td>21 %</td>
<td>21 %</td>
<td>21 %</td>
</tr>
</tbody>
</table>

As has been noted before, it seems that a capacity of less than 64 kbps should be sufficient to support fairly advanced integrated operations. This may be implemented on a satellite link for services between ship and shore (owner and/or SAR), but requires some kind of local area network between ships participating in a support operation for the first type of service.
Both AIS and a general digital radio carrier are possible technologies here. AIS may have problems to deal with the load, particularly in areas where AIS is used by a high number of other ships, but this is to some degree a question of traffic priority. A general purpose digital radio would be more convenient, but would require new equipment onboard as well as the capability of one or more ships to act as base station or – alternatively- a self organizing protocol similar to how AIS works.

The advanced emergency service operation is a very interesting area in e-Navigation that should receive more attention. One should in any case observe that these services only present a transient demand on communication bandwidth that is not necessarily dimensioning for a new e-Navigation carrier.

### 5.4.2 Nautical services

The nautical carrier group collects data transmissions related to public e-Navigation services. Thus, these services should be supported by coastal states to provide safety related services to own and international ships. This may imply that the services should be free of charge, but this is not necessarily the case. A summary of the services is presented in Table 22. The figures here are based on the low estimate of ships in the area.

#### Table 22 – Nautical services

<table>
<thead>
<tr>
<th>Additional navigational information</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTS coordination</td>
<td>100000</td>
<td>0,93 %</td>
<td>2,31 %</td>
<td></td>
</tr>
<tr>
<td>MIO</td>
<td>100000</td>
<td>0,67 %</td>
<td>0,67 %</td>
<td></td>
</tr>
<tr>
<td>PPU - VTS image</td>
<td>100000</td>
<td>80,00 %</td>
<td>80,00 %</td>
<td></td>
</tr>
<tr>
<td>Real time met-ocean</td>
<td>100000</td>
<td>0,22 %</td>
<td>0,22 %</td>
<td></td>
</tr>
<tr>
<td>Tug/mooring coordination</td>
<td>100000</td>
<td>1,85 %</td>
<td>4,63 %</td>
<td></td>
</tr>
<tr>
<td>Load/discharge coordination</td>
<td>100000</td>
<td>0,23 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port ENC updates</td>
<td>100000</td>
<td>44,44 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High accuracy berthing control</td>
<td>100000</td>
<td>2,31 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship reporting</td>
<td>100000</td>
<td>0,23 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coast state notification</td>
<td>100000</td>
<td>0,19 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port arrival notification</td>
<td>100000</td>
<td>4,63 %</td>
<td>2,31 %</td>
<td></td>
</tr>
</tbody>
</table>

The shaded areas are broadcasted services that do not depend on the number of ships in the area. The others are unicast and will scale with ship density. Table 23 and Table 24 list cumulative traffic demands for the low and high ship estimates respectively.

#### Table 23 – Cumulative nautical services - low

<table>
<thead>
<tr>
<th>Additional navigational information</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPU - VTS image</td>
<td>100000</td>
<td>80,00 %</td>
<td>80,00 %</td>
<td></td>
</tr>
<tr>
<td>Port ENC updates</td>
<td>100000</td>
<td></td>
<td>44,44 %</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>100000</td>
<td>0,33 %</td>
<td>8,57 %</td>
<td>15,01 %</td>
</tr>
<tr>
<td>Sum</td>
<td>100000</td>
<td>0,33 %</td>
<td>88,57 %</td>
<td>139,45 %</td>
</tr>
</tbody>
</table>

#### Table 24 – Cumulative nautical services - high

<table>
<thead>
<tr>
<th>Additional navigational information</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPU - VTS image</td>
<td>100000</td>
<td>80,00 %</td>
<td>80,00 %</td>
<td></td>
</tr>
<tr>
<td>Port ENC updates</td>
<td>100000</td>
<td></td>
<td>44,44 %</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>100000</td>
<td>0,33 %</td>
<td>16,26 %</td>
<td>29,13 %</td>
</tr>
<tr>
<td>Sum</td>
<td>100000</td>
<td>0,33 %</td>
<td>96,26 %</td>
<td>153,57 %</td>
</tr>
</tbody>
</table>
Dependent on the ambition level, one can accommodate most of the e-Navigation services with a carrier with a capacity of less than 50 kbps, even in highly congested waters. With more advanced services one may have to increase the capacity to somewhere below 200 kbps. Again, this is a moderate estimate that does not consider “advanced” services such as live video-surveillance or other high-bandwidth demanding services. On the other hand, if the communication carrier is being provided as a public service, one can argue that more demanding transmissions are done over other data links, e.g., commercially operated carriers.

5.4.3 Commercial services

Commercial services are included in the e-Navigation concept, but they may not necessarily use the same carrier as navigational and public services: This depends on the carrier capacities and the general usage principles employed by the coastal state.

However, the commercial service should preferably also be standardised. Ships do move from port to port and too many different technical systems will make it difficult to utilize new services in a cost-effective manner.

Table 25 lists the commercial services identified in section 4.2 with their respective communication demands. The figures are based on the low estimate of ships.

Table 25 – Commercial services

<table>
<thead>
<tr>
<th>Operational reporting</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyage orders and reports</td>
<td>100000</td>
<td>0,03 %</td>
<td>0,28 %</td>
<td>0,69 %</td>
</tr>
<tr>
<td>Commercial port call services</td>
<td>100000</td>
<td>0,74 %</td>
<td>1,85 %</td>
<td></td>
</tr>
<tr>
<td>Navigational data update (ENC)</td>
<td>100000</td>
<td>0,09 %</td>
<td>0,93 %</td>
<td>2,31 %</td>
</tr>
<tr>
<td>Operational reports</td>
<td>100000</td>
<td>0,08 %</td>
<td>0,83 %</td>
<td>2,08 %</td>
</tr>
<tr>
<td>Operating manuals, documents</td>
<td>100000</td>
<td>0,01 %</td>
<td>0,09 %</td>
<td>0,23 %</td>
</tr>
<tr>
<td>External maintenance and service</td>
<td>100000</td>
<td>0,09 %</td>
<td>0,93 %</td>
<td>2,31 %</td>
</tr>
<tr>
<td>Weather forecast</td>
<td>100000</td>
<td>0,09 %</td>
<td>0,93 %</td>
<td>2,31 %</td>
</tr>
<tr>
<td>Telemedicine</td>
<td>100000</td>
<td>0,19 %</td>
<td>0,19 %</td>
<td>0,19 %</td>
</tr>
</tbody>
</table>

All services except telemedicine are based on unicasts and will scale with the number of ships. Telemedicine is expected to be used at most by one ship in the area. The resulting cumulative demands for low and high ship numbers are listed in Table 26.

Table 26 – Commercial services, cumulative demands

<table>
<thead>
<tr>
<th>Operational reporting</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low ship estimate</td>
<td>100000</td>
<td>0,58 %</td>
<td>4,91 %</td>
<td>11,99 %</td>
</tr>
<tr>
<td>High ship estimate</td>
<td>100000</td>
<td>0,98 %</td>
<td>9,63 %</td>
<td>23,80 %</td>
</tr>
</tbody>
</table>

Again, the services are relatively low in bandwidth demands. In many cases one could probably supply this bandwidth as a commercially operated service besides the public navigational services.

5.4.4 Crew infotainment

The final group of services is crew infotainment which is listed below. These services are classified as special purpose as they need a dedicated channel per ship. Only the demand for one ship is listed, so it is the same for all ship areas.
Table 27 – Crew infotainment services

<table>
<thead>
<tr>
<th>Crew infotainment</th>
<th>bps</th>
<th>Tot BW OS</th>
<th>Tot BW Co</th>
<th>Tot BW PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew communication to family/home</td>
<td>100000</td>
<td>37.04 %</td>
<td>37.04 %</td>
<td>37.04 %</td>
</tr>
<tr>
<td>Crew training</td>
<td>100000</td>
<td>3.70 %</td>
<td>3.70 %</td>
<td>3.70 %</td>
</tr>
</tbody>
</table>

It is obvious that such a level of communication need fairly high capacity channels in areas with dense ship traffic. As an example, with 500 ships in the area, the total demand would be around 18 Mbps on a shared carrier.

Today this level of connectivity can be provided by VSAT or Inmarsat Fleet services at sea. Normally, both of these services will provide a higher total bandwidth in port and coastal areas. One could also use, e.g., GSM type or wireless metropolitan area networks, but the crew should in principle have access to the same service level independently of being in port or at high sea. Thus, high capacity solutions deployed along the coast or in port would normally be considered additional to the basic service level indicated in the table.

Also, the same principle of standardized access as was mentioned under commercial services, apply to this category.
6. Available and emerging ship communication technology

6.1 Satellite systems

Satellite systems will continue to be important for shipping at the high seas. Also in shore areas, satellites will continue 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\(^\text{10}\) and Globalstar\(^\text{11}\) 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\(^\text{12}\) 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 and line of sight to the satellite. It can prove difficult for a ship at high latitudes with roll or pitch movement or when located in narrow fjords 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 and other atmospheric phenomena.

Figure 8 – AMVER Plot April 2008 (© AMVER)

\(^{10}\) [http://www.iridium.com/](http://www.iridium.com/)

\(^{11}\) [http://www.globalstar.com/](http://www.globalstar.com/)

\(^{12}\) Atlantic Merchant Vessel Emergency Reporting [http://www.amver.com](http://www.amver.com)
However, developments in technology continue 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 the implementation of e-Navigation.

6.2 New shore based systems

Since around 2000, a series of new long range shore based digital technology has become available and able to provide relatively high data bandwidths to maritime users. The following sections will briefly look at some of these technologies. The table below summarizes the main characteristics in a very approximate fashion. Actual performance will often be a trade off between distance and capacity, particularly for carriers that rely on a good signal to noise ratio.

<table>
<thead>
<tr>
<th>System</th>
<th>Frequency</th>
<th>Range</th>
<th>Bandwidth per cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiMax, IEEE 802.16</td>
<td>2.3, 2.5, 3.5GHz</td>
<td>&lt; 50 km</td>
<td>70 Mbps (short range)</td>
</tr>
<tr>
<td>CDMA-450</td>
<td>450 MHz</td>
<td>&lt; 70 km</td>
<td>2.5 Mbps</td>
</tr>
<tr>
<td>Digital VHF (Existing)</td>
<td>156 MHz</td>
<td>&lt; 130 km</td>
<td>21.1 kbps (25 kHz)</td>
</tr>
<tr>
<td>Digital VHF (Suggested)</td>
<td>156 MHz</td>
<td>&lt; 130 km</td>
<td>153.6 kbps (50 kHz)</td>
</tr>
</tbody>
</table>

GSM type communication is not included in this overview although it may certainly be used in e-Navigation applications. The current structure with a high number of national service providers and the need for roaming agreements make it somewhat difficult to deploy this as a standard communication mechanism.

6.2.1 WiMax – IEEE 802.16

WiMax (Worldwide Interoperability for Microwave Access) is a relatively new “Metropolitan Area Network” (MAN) that can deliver digital services with high quality at long ranges. It has been deployed several places, e.g., on the coast of Norway\(^\text{13}\) and in the port of Singapore\(^\text{14}\). However, deployments are currently for non-mobile services as roaming is not supported. WiMax currently operates 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 as different agreements are needed with the different operators. This can easily become a similar problem to the one that currently exists with GSM. Also, it may be difficult to provide public services on the frequencies already controlled by different private operators.


\(^\text{14}\) Singapore WiMax network "Wiseport": General information is available from Infocomm Development Authority of Singapore (IDA) [http://www.ida.gov.sg/home/index.aspx](http://www.ida.gov.sg/home/index.aspx)
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].

6.2.2 CDMA-450

CDMA-450 is an adaptation of the CDMA-2000 standard to the 450 MHZ band [Noponen05]. This band was formerly used for mobile services, such as NMT 450 mobile phones, but is now being redeployed in many countries as a wide area wireless service. It can typically provide up to 2.4 Mbps bandwidth within large cells. A cell radius of up to 25 km has been mentioned. It 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.

6.2.3 Digital VHF

Digital VHF has been deployed along the complete Norwegian coast. Norway uses 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 specific system is in operation today and has already proven its application in fairly harsh surroundings. Increasing bandwidth as is suggested in the next section’s alternative technology will normally require a better signal to noise ratio and this will decrease effective range at a given transmission power.

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.

6.2.4 Suggested higher capacity digital VHF

A proposed alternative to the Norwegian solution uses another modulation scheme to increase data bandwidth. The proposal [ITU 5B/19] should give 153 kbps over a 50 kHz channel (two old VHF channels). However, this concept is not yet demonstrated in real world use. One may expect shorter range or lower reliability as signal to noise ratio will be more critical for a more demanding signal modulation.

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

6.3 Coverage in the Arctic region

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

Three options seem to be possible:

1. **LEO systems**: Iridium or other LEO systems can be used to provide coverage. This could also be interesting from the point of view of providing AIS coverage by equipping the satellites with AIS receivers.

2. **Molnya or Thundra 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 that would appear almost as one geostationary satellite appears closer to equator.

3. **HF based digital communication**: Due to low bandwidth requirements in these areas one could possibly make do with a HF or MF solution. However, these solutions offer very limited bandwidth.

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.

### 6.4 Private or public services

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 near future one can illustrate the available communication means as in Figure 9. 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. The cost of the equipment will in both cases be covered by the ship owner or operator.

![Figure 9 – Maritime communication facilities](image)

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.
6.4.1 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:

- **Dedicated low capacity carriers.** These include GNSS, EPIRB transmissions and similar services. These offer specialised services that will remain in an e-Navigation future and possibly also be expanded. However, bandwidth is limited and these services will not be able to handle extensive digital communication.

- **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 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, in congested waters there is little spare capacity for other purposes.

- **Inmarsat:** Inmarsat C and Fleet 77 are currently approved for GMDSS\(^\text{15}\) 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, LRIT position reports and safety alerts are generally “free”, but have limited size and capacity.

- **Radio:** These are DSC over VHF and HF/MF as well as NAVTEX over HF/MF. These carriers have limited bandwidth and re not really appropriate for extended e-Navigation services.

- **Digital VHF:** As discussed earlier in this paper, digital VHF is a new technology operating on frequencies licensed to maritime mobile communication. However, so far it has been deployed as a commercial service.

- **Broadcast services:** As has been mentioned, weather forecasts are transmitted as free broadcasts over satellite. Digital radio and TV via shore based radio or satellite could also be put into this category. This could be extended to cover parts of e-Navigation based on broadcast of data.

It is fairly clear that the current public services may have problems in supporting any significant new demands from e-Navigation.

6.4.2 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.

\(^\text{15}\) GMDSS – IMO specified services for Global Maritime Distress and Safety System
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 in some coastal areas.

- **WiFi/WiMax:** Wireless Internet networks are available in some ports. Drawbacks are very
  localized and limited availability. WiFi is currently being supplemented with WiMax,
  typically with much longer range and capacity and which may be more suitable for ship
  use. WiMax frequencies are, however, mainly owned by private companies which may
  make it difficult to apply in e-Navigation.

- **Broadcast services:** Television signals and weather forecasts are already being broadcast
to ship and DVB-RCS\textsuperscript{16} is starting to be deployed as an alternative to VSAT. This medium
may also be of interest to e-Navigation services as it may offer a low cost alternative for
transmission of large volumes. A similar type of broadcast via terrestrial radio is also an
alternative, but available 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.

### 6.4.3 Private-public partnerships

It may also be possible to establish private-public partnerships for new digital services after the
pattern of Inmarsat and IMSO (International Maritime Satellite Organization).

Inmarsat was established in 1979 as an internationally owned co-operative to provide mobile
satellite communications, initially to ships at high seas. Inmarsat has evolved to become the only
provider of global mobile satellite communications services for commercial and distress and
safety applications at sea, in the air and on land. In 1999, Inmarsat changed its corporate structure
from an intergovernmental organisation, to a commercial company with a small
intergovernmental secretariat (IMSO) to ensure that Inmarsat continues to meet its public service
obligations.

Similar constructions could be envisaged for some of the new frequencies that have been made
available for use in mobile communication, e.g., in 450 MHz and 790 MHz ranges. However, this
may already be too late as many of the frequencies are being auctioned off to private enterprises.

One could also imagine similar systems being used for LEO satellite systems, but the cost of
infrastructure is high and it is not clear if the benefits of such systems are large enough to make
the price acceptable.

\textsuperscript{16} DVB-RCS – Digital Video Broadcast, Return Channel via Satellite
7. Possible solutions for e-Navigation carriers

This chapter looks at some possible digital signal carriers for implementing new e-Navigation services. This will mainly focus on the general digital radio type of carriers, although other types will be mentioned from time to time.

7.1 Different possibilities in different areas

One issue that is critical in the selection of carrier or carriers is how well it performs in the different areas. Figure 10 shows diagrammatically how different radio systems could be used in the different sea areas. The areas included are the following:

- Inside port and port approach where VHF and other communication infrastructure are easily available.
- Coastal areas (sea area A1) where VHF radio and corresponding DSC services are available.
- High sea (sea areas A2 and A3) outside range of VHF, but with GEO satellite coverage.
- Arctic region (sea area A4) where neither VHF nor geostationary satellites are available.

The filled areas show where the system can be used as expected. The partly filled areas show where the system can be used under certain conditions. The light and dark blue areas represent commercial services while others are basically public services. The different groups are described, from the bottom and up, in the paragraphs below the figure.

**Figure 10 – Radio systems in different areas**

*VHF systems*, including AIS, voice and medium capacity digital radio will be available in coastal areas within range of VHF base stations on land. The systems can also be used outside land range, but only as for communication within one local radio cell. This applies to all systems, also digital radio as discussed in section 4.2.2.

*Special satellite services*, including AIS signals picked up by LEO satellites or a short messaging service (SMS) as suggested for Galileo and which is available on Inmarsat for, e.g., LRIT and SSAS functions. SMS services may be available in the Arctic if implemented over Galileo or other LEO or MEO satellites. Satellite AIS will probably not work well in congested waters, including ports and port approaches, due to the high number of AIS signals that it needs to pick up. This may also be a problem in certain costal zones, e.g., English Channel or Malacca Strait.
Commercial high capacity digital radio, as 3rd or 4th generation GSM, WiMax or WiFi will probably only be available in ports and port approaches. WiMax and GSM may be implemented also in coastal waters, but it is not clear if this is commercially viable in all areas.

**Inmarsat and VSAT** are based on GEO satellite systems and are available in all areas up to and including A3. Inmarsat may not be used where cheap land based radio is available, e.g., in ports, but this is purely a cost/benefit trade-off. VSAT has similar coverage, but is normally paid for as a fixed capacity data link and will normally be used also in ports.

**Low earth orbit** satellites like Iridium will provide coverage all over the world, also in the Arctic. The use of these systems will be based on a cost/benefit trade-off.

**Highly elliptical orbit** (HEO) satellites, e.g., in Molnya or Thundra orbits, can only be used in the Arctic. It will provide communication capabilities comparable to a GEO system when it is access from close to the Equator.

One conclusion from the diagram is that there is a certain degree of complementarities between the carriers in the different regions. Thus, it seems clear that more than one system needs to be considered for future e-Navigation implementation.

### 7.2 Coastal radio for long coast lines

Nations with long coast lines and relatively sparse ship traffic will probably not be able to provide high capacity (e.g., 3rd / 4th generation GSM or WiMax) digital shore based radio to ships in their coastal waters. For these cases one will have to rely on satellite or a lower capacity radio solution as, e.g., digital VHF. Digital VHF has been deployed in Norway as a commercial service with a coverage map as shown in Figure 11.

![Norwegian Digital VHF Coverage](image)

*Figure 11 – Norwegian Digital VHF Coverage © Telenor Maritime radio*
The figure shows the base stations and their coverage as per end of 2007. With slightly more than 60 base stations, this network covers one of the longest coastlines in the world. The coastline is 2 650 km long when measured as straight lines between the outermost part of the main land and about 25 000 km when fjords and major islands are included. Additional base stations on offshore installation give coverage also into the North Sea.

A VHF based system is even more interesting as it can use the same infrastructure as two other systems that are being deployed in most countries:

- **Automated VHF base stations**: As coastal radio stations are automated, communication via VHF is now being transmitted from a network of unmanned base stations to one or more central positions, typically co-located with the MRCC.

- **AIS base stations**: All European countries have deployed or will deploy a network of AIS base stations to monitor traffic along most of their coasts.

Both these services are also based on VHF and have the same physical coverage and general infrastructure requirements as digital VHF. The coincidence of these services is also visible in Figure 10. One should note that coordination of these services can dramatically reduce the cost of the infrastructure as power supplies, digital network backbones and masts can be reused for all three services.

This is also an interesting argument for developing nations where cost of infrastructure and equipment is critical. It is not likely that local short sea and coastal shipping in developing nations can afford satellite receivers. Thus, digital VHF may provide a low cost alternative to getting also these ships integrated into the e-Navigation concept.

### 7.3 Satellite or terrestrial systems for coastal communication

As pointed out in the previous section, the different carrier systems have different benefits and drawbacks and there may also be additional benefits in looking at combinations of carriers. While a satellite system in principle can cover both high seas and coasts, there are also some drawbacks to these systems. Table 29 summarizes some technical issues that are of interest in this context.

#### Table 29 – Summary of some criteria for selection of coastal carrier

<table>
<thead>
<tr>
<th>Issue</th>
<th>Inmarsat GEO</th>
<th>Private GEO</th>
<th>Private LEO</th>
<th>Public Terrestrial</th>
<th>Private Terrestrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity to ship movements</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Coastal coverage</td>
<td>O</td>
<td>O</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>High sea coverage</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>--</td>
</tr>
<tr>
<td>Real-time performance</td>
<td>--</td>
<td>--</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Cost for coast fleet</td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Cost for high sea fleet</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>--</td>
</tr>
<tr>
<td>Cost of infrastructure</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Coast state control</td>
<td>O</td>
<td>--</td>
<td>--</td>
<td>++</td>
<td>O</td>
</tr>
<tr>
<td>Safety of navigation</td>
<td>--</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Security</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Benefit for developing countries</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Load balancing coast/sea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
This is a subjective comparison and results will depend on many factors of which some is most likely not included in the below discussions. Thus, the reader is advised to take this table as a starting point and do his or hers own evaluation of the different issues.

The columns represent Inmarsat, other GEO type satellite systems (typically VSAT), LEO systems (currently Iridium) or a terrestrial system. The latter is divided into a public service, agreed upon internationally, and private services where different countries may have different frequencies, modulation techniques and cost models. HEO systems are left out as they only are of interest in the Arctic regions. The detailed discussions on each issue can be found in the following sub-sections.

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

### 7.3.1 Sensitivity to ship movements and coastal coverage

GEO satellites require a fairly sensitive antenna for high bandwidth communication. This will normally require the used of a stabilized dish antenna. This in turn, makes the antenna susceptible to ship movements, particularly for low inclinations at high latitudes. Thus, the reliability of GEO communication will be reduced as one goes north until it is more or less lost somewhere between 70 and 80 degrees latitude. Low antenna inclinations may also require the installation of more than one dish to cover cases where the ship itself or rather the superstructure shadows for the satellite.

A similar problem occurs in narrow and deep fjords where the mountain will shade out the view of the satellite. This problem gets more and more obvious as one goes north.

LEO satellites are not as sensitive to these phenomena as they normally rely on unidirectional antennas. However, the fjord shadowing effect is also an issue for LEO systems as only a relatively small number of satellites are visible at any one time. Being in a deep and narrow fjord will hinder the view of the satellites. This will not generally dependent on latitude. Also, one will only lose continuous access as some satellites will be visible form time to time, even in very narrow fjords.

Shore based systems will normally deploy additional base stations in areas with difficult reception. This can be seen, e.g., in Figure 11, where some fjords have dedicated base stations to give sufficient coverage. Note that the same problem will apply to VHF and AIS reception if the base stations are located at the same positions.

Thus, terrestrial systems can in general relatively easily avoid these problems by increasing number of base stations. However, if one relies on private systems, there will be a cost/benefit trade-off for the operator if full coverage shall be supplied. One cannot rely on commercial viability in all areas. For satellite systems it is an inherent problem, but less pronounced for LEO systems than GEO systems.
7.3.2 High sea coverage
Satellites are obviously necessary for coverage at sea. As was mentioned above, LEO systems give more benefits in that they can provide good coverage also at high latitudes where GEO systems may fail.

Terrestrial systems will not be able to give any coverage at high seas, except as a local communication cell, e.g., during emergencies or complex operations. This was discussed in section 4.2.2. If this functionality is going to be used, it must be based on a standard and, most likely, public communication system. For this reason, the public terrestrial system has got a slightly higher score than the private system.

7.3.3 Real time performance
GEO systems will minimum give a round trip delay of around 100 ms for each direction a message travels. Typically, this gives a delay in communication of 300 ms. LEO systems give much shorter delays as the orbit height is much lower. However, due to links to earth stations and from there to receiver, there will be some delay in signal transmissions. Terrestrial systems will typically give no delay.

A delay of up to 300 ms is normally not a problem and can be ignored in most cases. However, it is included here for completeness.

7.3.4 Cost for coastal fleet
The coastal fleet will only require communication equipment for sea areas A1. Thus, they will be able to operate without a satellite communication system. Costs of LEO terminals are normally lower than for GEO terminals with stabilized antennas and terrestrial system receivers are normally cheaper than that again. Thus, the coastal fleet will benefit from a terrestrial system.

7.3.5 Cost for high sea fleet
For the high sea fleet, the actual cost will depend on a number of factors. Some of these are:

- If e-Navigation is implemented over a costal system, the ship may have to invest in two data reception systems.
- If e-Navigation data is also available via public services, they may be picked up via Internet over satellite.
- LEO receivers will normally be cheaper than stabilized antennas for GEO systems.
- Many e-Navigation services will most likely have to be paid for by the user if it is implemented over Inmarsat or other private systems. Alternatively, the costs may have to be covered by the coastal state.
- Bandwidth cost of VSAT is normally lower than for Inmarsat. Equipment costs should be about the same. However, Inmarsat has better coverage than most VSAT providers.
• If a good and low cost terrestrial system is available and if a price per byte SatCom system is used, it may be cost effective to invest in a coastal receiver in any case to use that for some of the communication demands.

• For the previous bullet, a problem with a private system may be that the technical solutions may differ between ports so that a high number of receivers are necessary.

The weights indicated in the table have tried to measure these issues against each other, but the actual trade-off will be different dependent on the details of cost and availability parameters.

### 7.3.6 Cost of infrastructure

The infrastructure costs will also be dependent on a number of factors. The weights in the table have attempted to cover the following issues:

- Private systems including Inmarsat are operated without direct cost to the coastal state, other than traffic costs. A public network must be built and maintained by the coast state.
- A significant traffic cost may be incurred by end user or coastal state when using private services. Public networks provide the service for free, when operational costs are covered by other budgets.

Thus, it is not clear what gives any highest benefit. One should also keep in mind that, e.g., a VHF based infrastructure is relatively low cost (see section 7.2).

### 7.3.7 Coastal state control

As the coastal state (or possibly 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 for private systems, including satellite systems. One can give some credit to Inmarsat as they are to some degree controlled by the IMSO convention. Correspondingly, one can also argue that a local private operator of a coastal network may to some degree be controlled by agreements between the governmental agencies and the operator.

### 7.3.8 Safety of Navigation

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 argument used for this was mainly that two independent systems increase the chances that at least one will work in an emergency. Another argument was that many smaller vessels did not have access to Inmarsat services at all.

By providing added services over VHF, the system may be much more utilized 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 public terrestrial based system will further enhance maritime safety by providing more support for the VHF infrastructure.
Also, a GEO system requires a stabilized antenna that may fail in critical situations, e.g., when the ship has a high list or is at high latitudes. Thus, LEO systems and terrestrial systems provide a higher benefit, from this perspective.

### 7.3.9 Security of infrastructure

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). Again, different arguments can be provided as benefits or drawbacks for the different solutions:

- Inmarsat as a system is fairly robust and has been built to cover the whole world. Thus, one can argue that it may be more robust than other private systems.
- Shore based infrastructure is in general more susceptible to direct physical attacks.
- Signal to noise ration of satellite systems may make them easier to jam.
- Relatively simple VHF data transmissions may be easier to jam or fake than more advanced modulation techniques used on other carriers, e.g., WiMax.
- It may be relatively low cost to provide redundancy for simple systems like VHF based digital radio.

This is attempted summarized in the initial table, but weights will vary dependent on actual technical solutions.

### 7.3.10 Benefits for developing nations

For developing nations with limited possibilities for installing expensive equipment on local ships, it will be highly preferable to develop a terrestrial system – particularly if this is built on international standards. 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 so much in this context. Private operation can be assumed to reduce initial investments while increasing operational costs. However, it may be a point that a public service may easier provide free or low cost services to coastal fleet vessels that otherwise could not afford digital communication.

Note also the potential benefits of basing such a system on VHF technology as discussed in section 7.2.

### 7.3.11 Load balancing coast/high sea

As Chapter 5 showed, there is a significant difference in communication demands near coast or in port and compared high seas. A combined satellite/terrestrial system would be able to utilize that difference to get a better load balancing.
8. Conclusions and recommendations

This chapter contains some general conclusions and recommendations that the authors’ have made from the results presented in this report. This is obviously not the answer to any questions, but a summary of the authors’ observations. The reader should go through the details and verify that the assumptions correspond with the local conditions before any decisions are made.

8.1 AIS bandwidth is fully utilized

AIS capacity is fairly close to maximum utilization, at least in congested waters, and should be reserved for real-time navigation data. There are limited possibilities to add more data to this carrier, unless new frequencies are added. Thus, AIS may not be a candidate for all new e-Navigation services. However, AIS should be used for short real-time navigation related data, as far as possible.

8.2 Arguments for use of terrestrial carriers for e-Navigation

Purely navigational related services (excluding VTS image and ENC updates) can be serviced by a communication channel of about 30 kbps. This could in principle be done by adding four to five channels to the AIS system, but it could also be done by using two standard digital VHF channels.

A total cumulative bandwidth of around 200 kbps seems to be sufficient to cover all relevant e-Navigation services, even in port. If VTS image and ENC updates are kept out, it should be sufficient with 100 kbps even when some crew infotainment services are included. These services could respectively be provided over dedicated data links or private services.

Capacity demands are very much higher near coast and in port than at open sea. Thus, a shore based communication infrastructure can be used to cover coast and port approaches and by that complement satellite systems which in any case are necessary at open sea.

In addition, one will obviously also need to use satellite systems for ships that are at the high seas. Although new systems are continuously being launched, it seems that Inmarsat still will have a central role for safety at sea.

8.3 Standards are required

Shipping is international and if a terrestrial carrier is selected, one should aim for a solution that can be standardized world-wide. Some possibilities have been listed in the report:

- **Digital VHF**: This seems to have sufficient bandwidth, is fairly low cost to build and can operate on frequencies that are already allocated to mobile marine use.

- **450 MHz or 790 MHz ranges**: Some frequencies have been newly allocated to mobile use from the bands previously used for television. By using, e.g., WiMax or CDMA technology and standardizing this world wide, one could get a new high capacity e-Navigation carrier.

- **Public-private partnerships**: It may be possible to establish agreements between private operators and public authorities on using established frequencies and modulation.
techniques for a combined public and private e-Navigation services. Good examples are WiMax at one or more of the suggested frequencies.

Digital VHF is the by far easiest standardisation task. Other approaches will have to fight very strong private and commercial interests. However, WiMax, in particular, seems to provide very interesting range and capacity for maritime use.

8.4 Benefits of VHF as carrier
In particular, we would like to point out that there are some special benefits in using digital VHF for a new carrier. One is the use of frequencies already allocated to mobile maritime use, others were discussed in section 7.2 and in 7.3.10. For developing nations, in particular, there are there interesting possibilities in this technology.

8.5 Support for emergency management and general coordination at high sea
Section 5.4.1 discussed the possibility of using a terrestrial communication system also at high seas, either for emergency management or as a general purpose mechanism for communication and coordination between ships in close vicinity. This could easily be based on AIS although message sizes are relatively short.

However, if a digital radio system is used, one should consider how one or more ships can act as base stations or, alternatively, how a self-organising system could be set up. The digital VHF system has fairly high integrity and robustness and could be a good example of such a system.

8.6 Authentication should be included
The MMSI (maritime Mobile Service Identity) follows most of the GMDSS messages like DSC, AIS and LRIT messages. Many of the suggested e-Navigation services will also require some form of authentication of the sender.

Today, it is easy to fake the MMSI number and “impersonate” any ship. This is normally a soft configuration in the equipment, at best protected by a configuration password. Thus, although the MMSI normally is reliable, it cannot be used for legally binding or other forms of critical identification. An e-Navigation services that may need authentication is, e.g., messages related to port clearance. In this case it is important both for security and safety reasons as well as for possible invoicing, e.g., of fairway or lighthouse dues that the sending ship can be identified.

Thus, future e-Navigation carriers should include mechanisms that can be used to authenticate the sender. This would be an extremely valuable mechanism for many of the e-Navigation services. One should in any case base the authentication on the MMSI as that is the main identification used today.
9. References


[eLoran] The Case for eLORAN, Research and Radionavigation, General Lighthouse Authorities of the United Kingdom and Ireland, 8th May 2006

[eNAV2] IALA draft liaison statement to ITU: VHF radio system and equipment for the exchange of data and e-mail on maritime appendix 18 channels under wrc-07 agenda item 1.1.4.

[ERC 2002] European Radiocommunications Committee (ERC) - Report 25, The European table of frequency allocations and utilisations covering the frequency range 9 kHz TO 275 GHz, Lisbon, January 2002 as amended.


[ISL07] ISL Shipping Statistics Yearbook 2007, ISSN 0721-3220


[ITU 5B/19] Document 5B/19, Working Party 5B ,[PRELIMINARY] DRAFT REVISION OF RECOMMENDATION ITU-R M.1842: Characteristics of VHF radio system and equipment for the exchange of data and electronic mail in the maritime mobile service Appendix 18 channels

[ITU M.1842]: ITU Recommendation M.1842 – Characteristics of VHF radio system and equipment for the exchange of data and electronic mail in the maritime mobile service Appendix 18 channels.

[Alexander 2003] Marine Information Objects (MIOs) and ECDIS: Concept and Practice, U.S. Hydrographic Conference, 24-27 March 2003, Biloxi, MS, Dr. Lee Alexander


[MSC 1091] MSC/Circ.1091, 6 June 2003, Issues to be considered when introducing new technology on board ships.


[NAV 53/13/22] NAV sub-committee, 53rd session, Agenda item 22, 14 August 2007, Report to the Maritime Safety Committee


