INTERNATIONAL MARITIME ORGANIZATION

E

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Agenda item 11

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DEVELOPMENT OF AN E-NAVIGATION STRATEGY IMPLEMENTATION PLAN

Report from the EfficienSea Project

Submitted by Denmark, Estonia, Finland, Norway, Poland and Sweden

SUMMARY

Executive summary:	The report contains information on e-navigation services/functions which expand the solutions identified in appendix 2 of the input to COMSAR 16 from the e-navigation correspondence group, which again will meet the originally identified e-navigation user needs. The services/functions are the outcome from an e-navigation test bed in the Baltic Sea Region which has been carried out by work package 4 on e-navigation in the EU co-funded project EfficienSea.
Strategic direction:	5.2
High-level action:	5.2.6
Planned output:	5.2.6.1
Action to be taken:	Paragraph 73
Related document:	COMSAR 16/11, annex 2

Introduction

1 The purpose of this input document is to explain some e-navigation services/functions which expand the solutions identified in appendix 2 of the draft input to COMSAR 16 from the e-navigation correspondence group, which again will meet the originally identified e-navigation user needs. The services/functions are the outcome from an e-navigation test bed in the Baltic Sea Region which has been carried out by the EU co-funded project EfficienSea.

2 The services/functions have been derived from a process quite similar to the e-navigation strategy formulated by IMO.

Identification of user needs

3 A number of tasks were undertaken in order to identify a number of user needs. Of course, it has not been the projects goal to identify all relevant user needs within e-navigation; however a number of needs with particular relevance to the participating organizations have been identified. The methods for identification have included: interviewing mariners, having sessions with mariners in focus groups and conduction of simulations during which user needs were observed and identified by usability experts (mariners should read mariners and other relevant users, also shore users).

Architecture

4 A draft architecture was established in order to demonstrate possible e-navigation services. It consists of communication systems, ship infrastructure, shore infrastructure, data modelling and data encoding.

Gap analysis

5 Not particularly relevant for the test bed trial.

Implementation

6 Based on the identified user needs and the draft architecture, prototype services were developed and the solutions were installed at test sites, mainly a fleet of various types of vessels. The services include:

- getting prognosis for meteorological and oceanographic parameters on a vessels route to the vessel;
- showing MSI in the navigational chart following a new format for data and portrayal;
- transmitting vessels intended route to other vessels and shore users through AIS;
- transmitting route suggestions from shore user (VTS) to vessels; and
- sending search areas to be used for SAR.

Review lessons learned

7 The value of the services and functions has been assessed by methods similar to those used to identify the original user needs, i.e. interviews, focus groups and simulations. The results will be fed into the IMO e-navigation process. This COMSAR input presents the first results from this test bed to be given to the IMO process.

8 In the following each service/function will be described in greater detail. As this input is for COMSAR, emphasis will be on architecture (in particular communication) supporting the services and functions. Portrayal and functionality will be expanded further in future input for the NAV Sub-Committee.

Discussion

Draft e-navigation Architecture

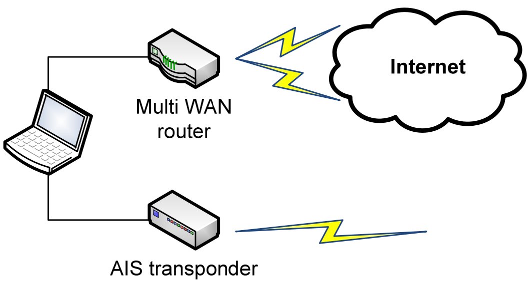
9 The e-navigation can be seen as a distributed system with components on board ships and on shore. In order to demonstrate possible e-navigation services a draft e-navigation architecture was needed to establish functional links between these components.

Communication systems

10 Suitable and attainable communication systems were needed for the draft architecture. It was recognized that we couldn't merely abstract any communication system as a functional link on which the same services can function in the same way. Each communication system has characteristics that dictate possibilities and limitations on the services using the system. Two communication systems with different characteristics were chosen, AIS and Internet. Internet provided by the technologies mobile broadband, satellite, and VHF-data.

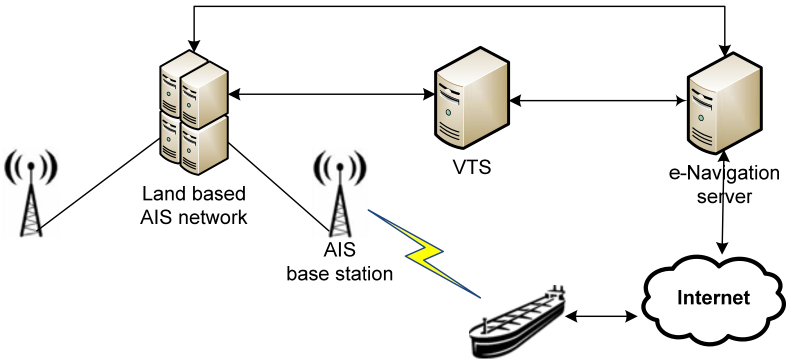
Ship infrastructure

11 The ship infrastructure consists of a software application running on an ordinary PC connected to the Internet and to the AIS transponder through the pilot-plug. The software application is open source and based on OpenMap, an open source platform for showing geographical information including electronic navigational charts. To use multiple link technologies for the Internet, a so-called Multi WAN router was used to shift between multiple connections based on availability, costs and connection requirements (e.g. bandwidth).



Shore infrastructure

12 The shore infrastructure consists of the following components: e-navigation server, VTS system and land-based AIS network. The shore components are inter-connected by the Internet. The e-navigation server delivers services in the form of request-response based web services to the ship applications and the VTS system. The e-navigation server and the VTS system use the land based AIS network to receive and send AIS messages.



Data modelling and encoding

13 Data modeling for the information to be transferred between components was done using UML. The data encoding used is XML for data communicated over the Internet. Data encoding for AIS is in the form of application specific messages.

14 It is considered straightforward to define the current e-navigation prototype services using S-100.

15 Choosing and implementing a draft e-navigation architecture raised many considerations and ideas for a future e-navigation architecture. The annex to this document shows details and considerations on how a future architecture could be arranged.

Maritime Safety Information (MSI)

16 Solution No. 6 in Report from the e-navigation CG to COMSAR 16 (COMSAR 16/11, annex 2) suggests the Integration of available information in nautical graphical displays, among those MSI, AIS, charts, radar, etc.

17 The EfficienSea project has in connection with this, investigated possible solutions concerning Maritime Safety Information and has developed and tested alternative ways of collection, promulgation and presentation of MSI with good results.

18 MSI is today promulgated in text or voice via SafetyNET, NAVTEX, coast radio stations and is in some countries accessible on the Internet. All of above methods are time-consuming for the Mariner and there is a risk of human error.

19 Some navigation equipment developers are working on systems taking existing messages from NAVTEX broadcasts and transferring them into georeferenced warnings for presentation on navigation displays. There are many advantages in this approach building on already established systems but a number of limitations still exist.

20 In the EfficienSea project both systems for shipside, shore side and communication have been developed and tested to ensure holistic solutions and an all encompassing approach to the task.

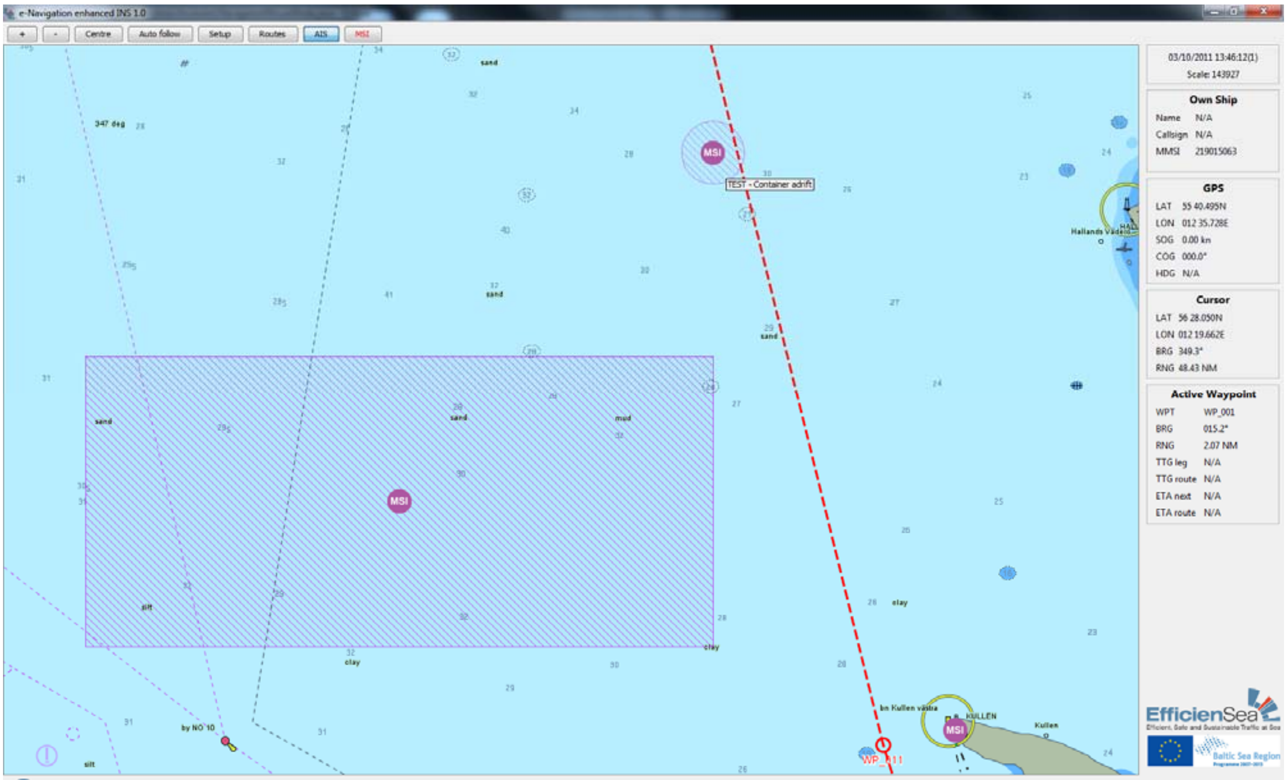
21 All MSI messages are collected in a common MSI shore database maintained and updated by the National Coordinators in a NAVAREA or Subarea. The MSI database contains all Maritime Safety Information promulgated today and additional information such as detailed position information, information for smart filtering and for proper presentation on vessel displays.

22 The Maritime Safety Information is transmitted to test vessels capable of receiving georeferenced MSI messages via Internet or other data link and also via traditional systems such as NAVTEX.

23 On board the MSI messages are received by the ship system and are presented directly on the navigation display with a specific MSI symbol. It is possible to access MSI text and additional information by mouse click and by mouse over a short describing text is displayed for easy assessment by the Mariner.

24 All vessels receive ALL Maritime Safety Information. To avoid overload of information it is possible for the Mariner to filter MSI messages by distance from own vessel and route so only relevant messages are displayed.

25 In the vessels navigation system it is possible for the Mariner to handle received MSI, e.g. get an overview and acknowledge assessed messages.



Example: Presentation of Maritime Safety Information on navigation display

26 Feedback from test users is very promising. The strengths and weaknesses of the MSI service have been discussed in a focus group session gathering test users. The focus group included 8 active seafarers, one pilot and 7 officers and masters from three vessel types (tanker, buoy tender and passenger ferries) all part of the EfficienSea test fleet. The test users all have practical experience in use of the MSI service from their respective vessels.

27 The focus group showed that different users have different needs, both regarding ship type, role on board and waters navigated. The MSI service fulfils this well.

28 The weaknesses all relate to specific details in the portrayal of MSI in the prototype; e.g. that a pop-up window hides parts of the chart area, weak chart presentation of acknowledged MSI messages and missing navigational warning ID number when displayed on chart.

29 The strengths identified by the focus group are linked to the overall concept of making MSI messages available to the Mariner on the navigation system, e.g. the go-to and filter functions, receiving updated information on chart display and that it actually makes the Mariner read the MSI messages.

30 Also discussed was the overarching demand that the data (server, shore information) has to be completely reliable or it will have negative impact on use of services. Not knowing about reliability lowers usability.

31 All participants were of the opinion that the MSI service is valuable and should be developed further. The service is filling a current information gap and if the weaknesses are worked with, the service will improve and assist the navigators in their daily work.

Meteorological and Oceanographic data on route (METOC)

32 Referring to COMSAR 16/11, annex 2, solution number 6 of the report from the IMO Correspondence Group, there is a suggestion to integrate available and relevant information into nautical graphical displays. This integration should also include meteorological and oceanographic information.

33 The EfficienSea project has in connection with this developed and tested alternative ways of promulgation and presentation of METOC on route information with good results. Both systems for shipside, shore side and communication have been developed and tested to ensure holistic solutions and an all encompassing approach to the task.

34 The METOC on route service provides the Mariner with up-to-date weather warnings, weather forecasts and oceanographic prognosis. The information is presented on vessels navigation display along vessels route on demand (see figure below).

35 The service is an alternative to radio broadcasts, NAVTEX transmissions and similar traditional systems. The information received via the METOC service is vessel and route specific and the Mariner will have only METOC information relevant to present or planned route displayed.

36 When route has been created by the Mariner, it is possible to request METOC information from the shore service. The METOC shore service calculates the corresponding METOC data based on latest forecast/prognosis. A forecast/prognosis specific for vessels route is returned and displayed by intuitive symbols along the route on vessels navigation display.

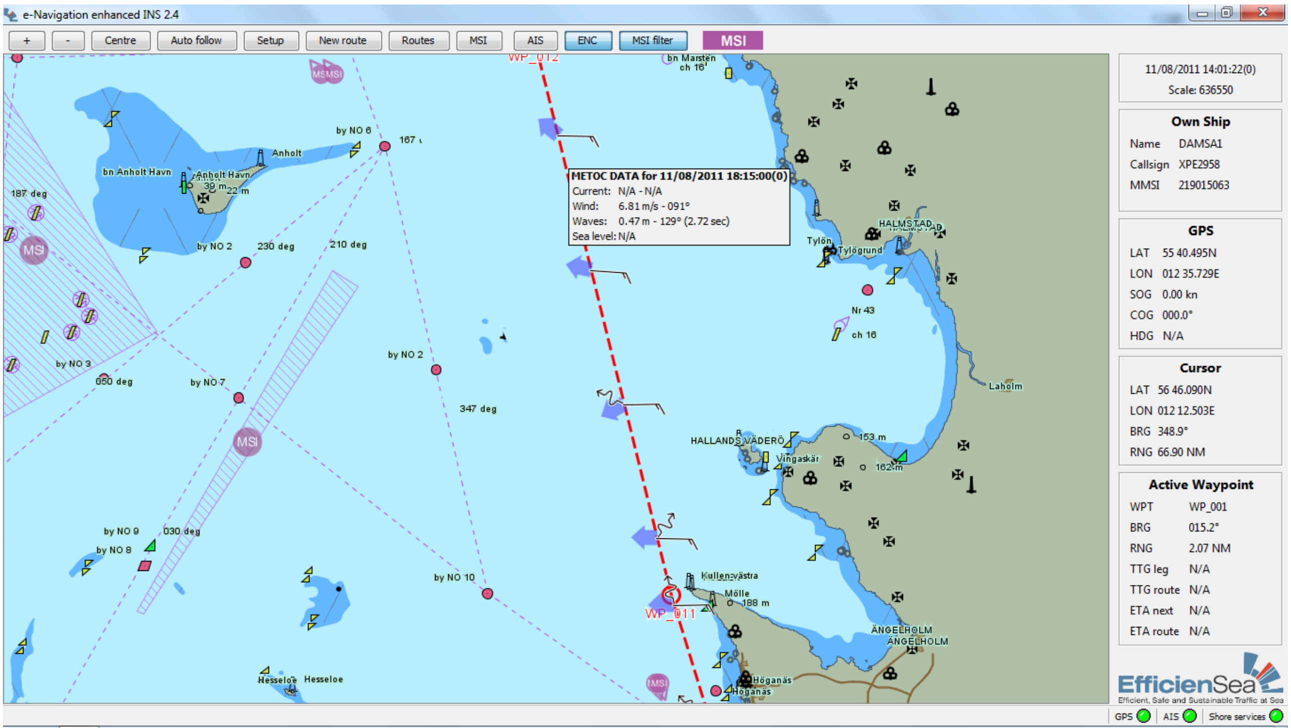
37 At present following data is available:

- wind force and direction;
- wave height and direction;
- current speed and direction; and
- water level.

38 By mouse-over it is possible to have the actual values for above data presented.

39 Not all vessels have same limitations on wave heights, wind force and current and therefore a vessel specific METOC warning module has been implemented. It is possible to enter user defined limits in the warning module, e.g. if wave heights reach certain levels or wind force exceeds a certain limit, and the system will warn the Mariner if these limits are exceeded.

40 When navigating on a route, the system automatically checks for updates every 15 minutes – if there is a new forecast/prognosis or if the vessel has changed speed and thereby arrival times at planned waypoints.



Example: Presentation of METOC on route on navigation display

41 Feedback from test users is promising. The strengths and weaknesses of the METOC service have been discussed in a focus group session gathering test users. The focus group included eight active seafarers, one pilot and seven officers and masters from three vessel types (tanker, buoy tender and passenger ferries) all part of the EfficienSea test fleet. The test users all have practical experience in use of the METOC service from their respective vessels.

42 The focus group saw the METOC service as an interesting service; that it was good to see the weather along vessels route – but it should not clutter up the screens. Information should be available but not necessarily visible.

43 Besides cluttering of the screens, the reported weaknesses included some difficulties in symbol interpretation and issues regarding the availability of the service. The latter issue is however believed to relate to differences in the communication capabilities of the various test vessels.

44 Also discussed was the overarching demand that the data (server, shore information) has to be completely reliable or it will have negative impact on use of services. Not knowing about reliability lowers usability.

45 In contrast to the very positive feedback on the MSI service, the participants were more critical towards the METOC service. six of the eight participants were in favour of such a service, but further development is needed, e.g. the ability to request METOC information in specific locations.

Route Exchange

46 Referring to COMSAR 16/11, the report from the IMO Correspondence Group, it is suggested a real-time short-range ship-ship and ship-shore exchange of navigation plan and intention.

47 The EfficienSea project has in connection with this developed and tested route exchange functionalities with good results. Both systems for shipside, shore side and communication have been developed and tested to ensure holistic solutions and an all encompassing approach to the task.

48 Route exchange can be divided into two separate services:

49 Exchange of intended route, where vessels may broadcast their intended route to other vessels and shore-based users for presentation on navigation display/traffic management display.

50 Route Suggestion, where a shore-based user can send a suggested route to a vessel.

51 The Route Exchange service should be seen as a supplement to traditional VHF voice communication which is subject to misunderstandings due to language problems, lacking situation awareness, wrong interpretation of surroundings and human error.

Exchange of Intended route

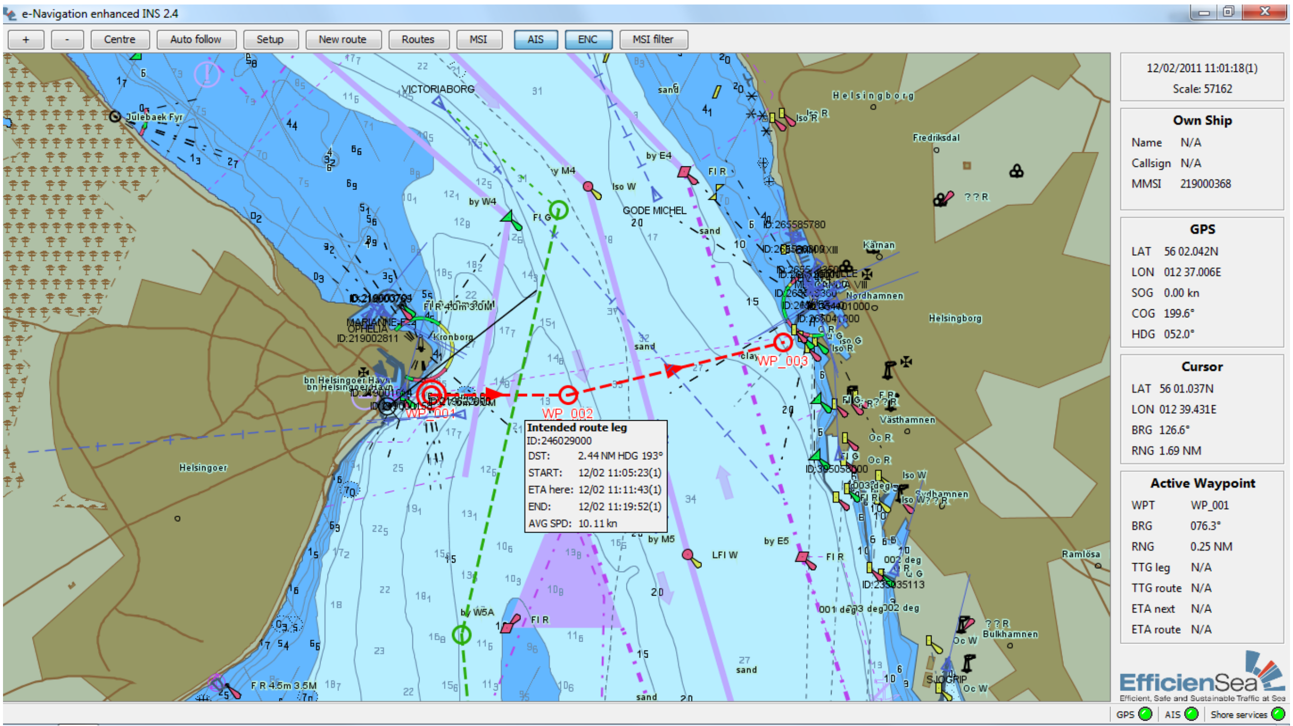
52 "What is your intention?" is a common question over the VHF when two ships are in doubt of each other’s intentions. The Exchange of Intended route service makes it possible for vessels and shore authorities to see other vessels intended routes presented on their navigation display or in their traffic management system.

53 When ships are heading into conflicting situations, they are expected to solve the situation using COLREGS. COLREGS are supposed to unambiguously label one of the ships the stand-on vessel and the other the give-way vessel. But due to misunderstandings this is not always the case, as can be seen from different accident reports.

54 The Exchange of Intended route service as tested works as follows: When a vessel is navigating on an active route in its navigation system the route is automatically and continuously broadcasted via AIS. All AIS receivers within range receive vessels route; waypoints and corresponding arrival times. The received intended routes are presented on vessels navigation display by click on the target on screen in a similar way as AIS details are presented.

55 A future development of the service could be an automatic CPA/TCPA filter where vessels intended routes are shown if CPA/TCPA value is less than a predefined limit.

56 With the service the VTS centres have the possibility to see vessels intentions and foresee close quarter situations or congestion in narrow passages.



Example: Presentation of other vessels Intended Route on navigation display – close quarter situation in TSS Helsingør

57 The initial results from the user tests and ship simulation indicate that there is a big potential for such a functionality, but that the concept must be further developed before an e-navigation standard can be proposed.

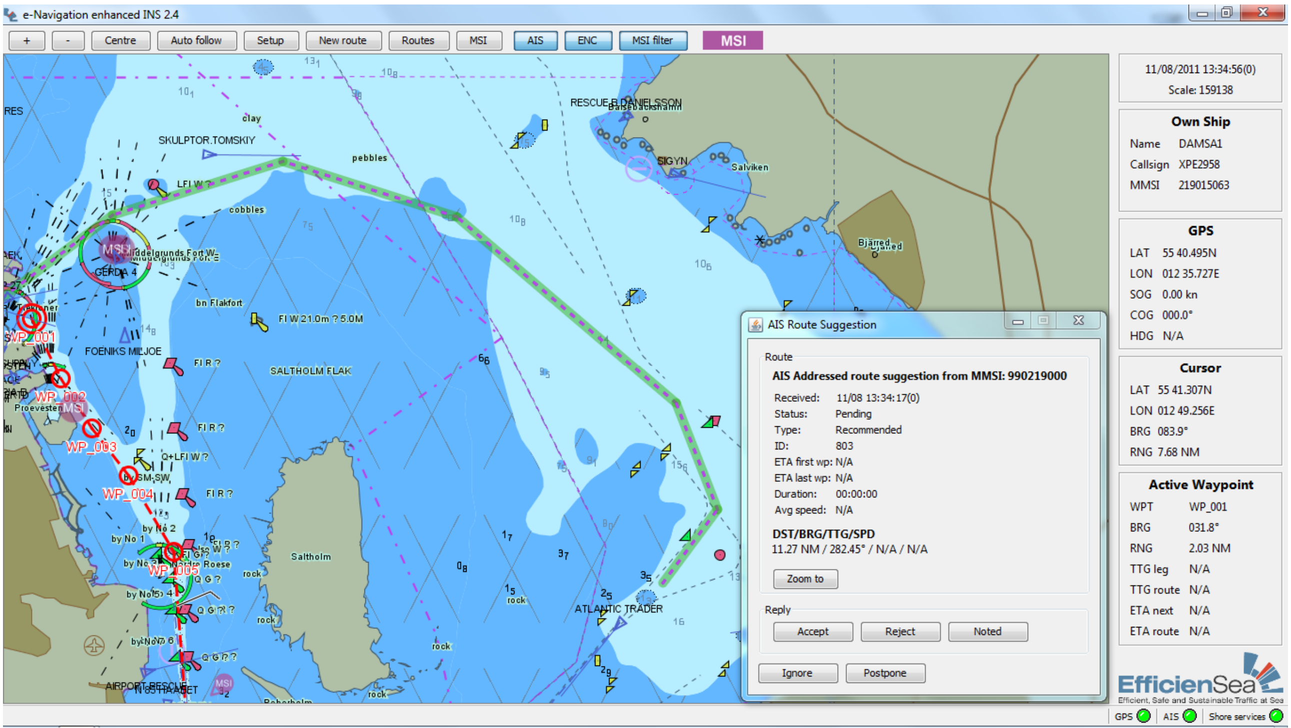
Route Suggestion

58 In addition to the capability of vessels exchanging intended route, there should also be a possibility for shore users (e.g. VTS) to transmit route suggestions to vessels.

59 The route suggestion service makes it possible for shore authorities (e.g. VTS centres) to send route suggestions electronically to vessels for presentation on navigation display. The service should be seen as a supplement to traditional voice communication which is both time-consuming and presents a risk of misunderstanding.

60 The route suggestion is received on board by the system and is automatically presented on the navigation display together with an explanatory text box (see below figure).

61 The Mariner may choose to Accept, Reject or Note the suggestion in which case a reply message is returned to the issuing authority. If the Mariner Accepts the suggested route he/she has to check and change vessels active route to match the suggestion.



Example: Presentation of VTS Route Suggestion on navigation display

62 As with the exchange of intended route, initial results indicate a great potential, but also that the concept needs further maturation before a final standard can be suggested.

63 Further work on route exchange, based on the results of EfficienSea, is now performed in the EU sponsored project MonaLisa.

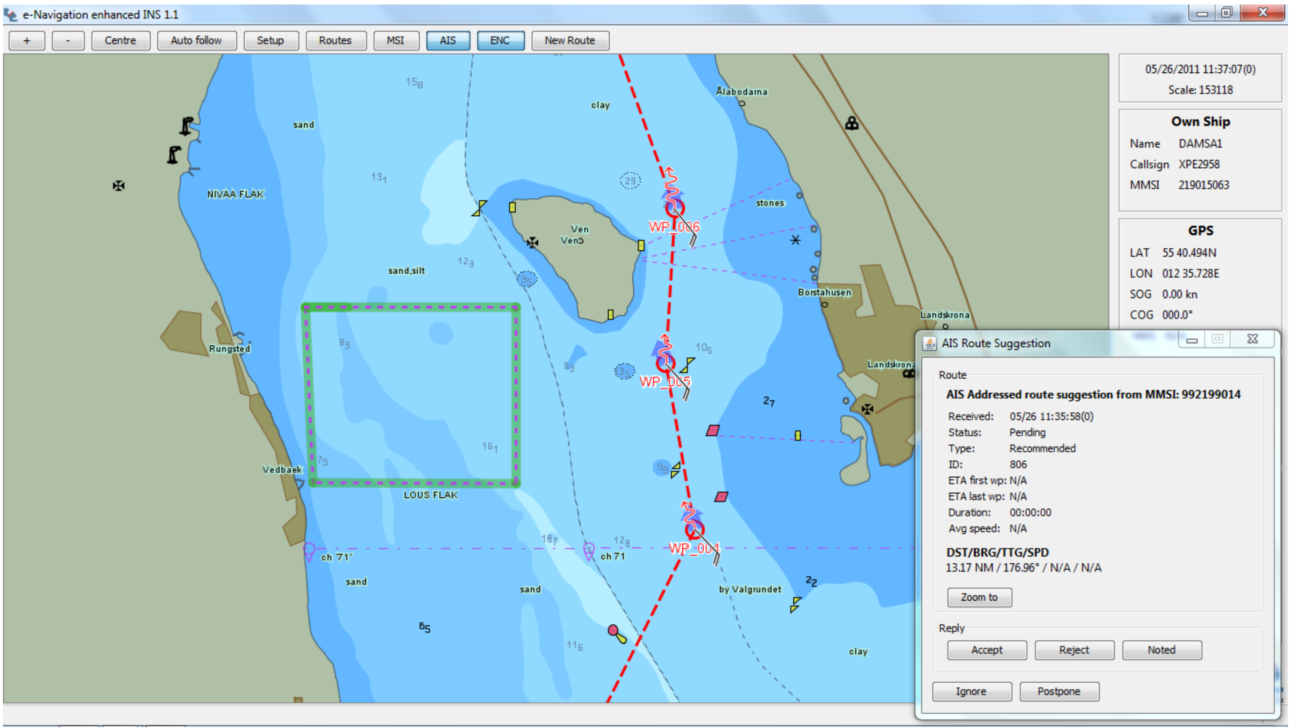
64 In connection with the continuous work on the suggested route service, the responsibility of the Mariner should be taken into consideration (reference to the STW watch keeping procedures).

Search and rescue tests

65 Referring to COMSAR 16/11, annex 2, solution number 29 of the report from the IMO Correspondence Group, it is suggested to have an Automated SAR communication and data coordination network.

66 The EfficienSea project has in connection with this developed and tested prototype SAR functionalities with good results. Both systems for shipside, shore side and communication have been developed and tested to ensure holistic solutions and an all encompassing approach to the task.

67 EfficienSea tested the prototype in a large Search and Rescue exercise with participation of 10 vessels, a rescue helicopter and JRCC with extremely promising results and positive feedback from subjects and SAR authorities. The prototype SAR functionalities were in the tests building on the route exchange functionalities described earlier in this document. Search areas were transferred electronically from shore to Search and Rescue Units (SRU) for automatic presentation on navigation displays.

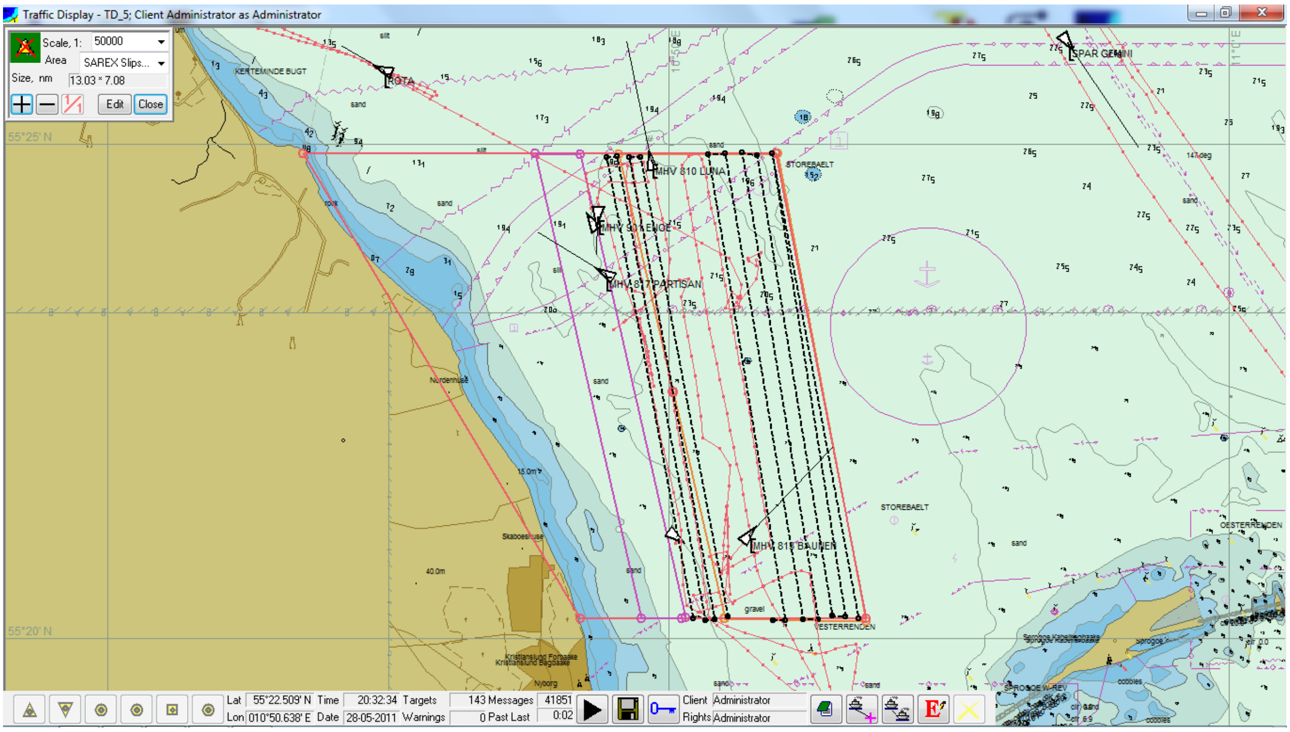


Example: Presentation of received SAR search area on navigation display

68 The functionality should be seen as a supplement to traditional VHF voice communication which is often the only communication link available to vessels. Transferring SAR information and especially positions, areas and tracks, is time-consuming and is subject to misunderstandings due to human error, language problems, lacking situation awareness and wrong interpretation of surroundings.

69 After reception of the search area on the SRU's, search patterns were calculated on board and entered into the navigation system. The intended search pattern was then broadcasted automatically to other SRU's, OSC and shore authorities – see Exchange of Intended route description earlier.

70 With the service, the OSC and/or shore authorities have a full overview of the search and rescue operation, to see SRU's planned search patterns and with the passed track functionality their progress in it.



Example: Presentation of OSC screen with search areas transmitted to SRU's, SRU's search patterns and their passed track (VisSim Norway)

71 The preliminary results of the SAR functionality tests are very promising but further development and studies need to be conducted before giving any final conclusions and recommendations.

Service functions

72 Specific services/functions have been tested based on a test bed driven approach which ensures a truly user driven approach to e-navigation. Some services are relatively developed and matured (MSI & METOC), whereas others need further maturation (Route exchange). Further input will be given on the herein-mentioned services and functions at a later stage (NAV 58), and further functions and services will likewise be included.

Action requested of the Sub-Committee

73 The Sub-Committee is invited to note the information provided, in particular:

.1 paragraphs 11 to 12 (ships and shore infrastructure);

.2 paragraphs 13 to 15 (data modelling and encoding);

.3 paragraphs 26 to 31 (the value of the MSI service);

.4 paragraphs 41 to 45 (the METOC service);

.5 paragraphs 57, 62 to 63 (the route exchange service as a supplement to VHF voice communication; and

.6 paragraph 64 (the responsibility of the mariner concerning route suggestion).

***

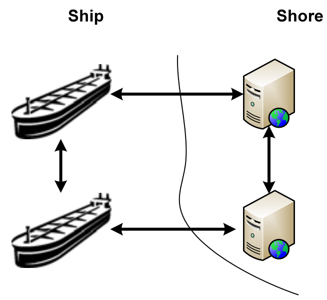
ANNEX

e-navigation architecture

An implemented prototype architecture and considerations on e-navigation communication

Introduction

In a holistic approach, e-navigation can be seen as a distributed system with components on ships and components on shore. In order to demonstrate possible e-navigation services, a prototype e-navigation architecture was needed to establish functional links between these components. The prototype architecture includes a data model for the information to be transferred, data encoding, communication systems, shore infrastructure and ship infrastructure.



0-1 Basic architecture with interconnected ship and shore components

The purpose of this annex is to describe the prototype architecture we have chosen and the considerations behind it, experiences from using the architecture and thoughts on the future.

The annex is somewhat more technical than the previous documents on e-navigation. It is felt that at this stage of the overall e-navigation process it is necessary to describe things in more technical terms, in particular when it comes to the matter of architecture/communication.

The first section offers some general thoughts on e-navigation communication aspects. The section applies common theory in the field of computer science to the concept of e-navigation.

The second section describes the prototype e-navigation architecture developed in the EfficienSea project, lessons learned and considerations regarding a future e-navigation architecture.

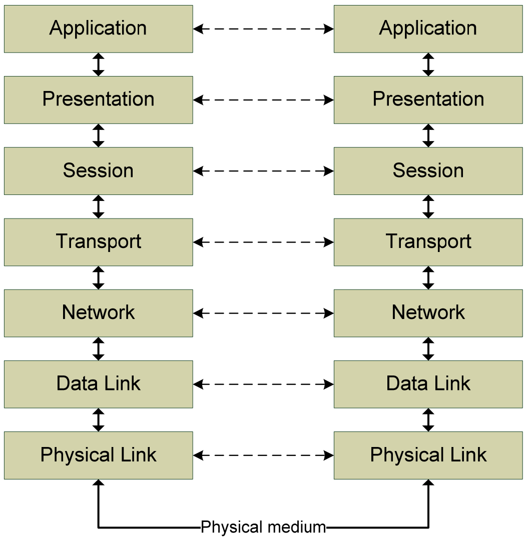
General thoughts on e-navigation communication

Suitable and attainable communication systems were needed for testing e-navigation prototype services. It was recognized that we couldn't merely abstract any communication system as a functional link on which the same services can function in the same way. Each communication system has characteristics that dictate possibilities and limitations on the services using the system. That is in terms of bandwidth, reliability and topology (e.g. the ways in which ship and shore can communicate with each other).

This section describes the investigation of two communication systems with very different characteristics: Internet and AIS. The investigation guided the choice of communication system for the implemented services as well as the identification of communication systems that may be needed in future.

OSI model

To describe a communication system it is convenient to use the Open Systems Interconnection model (OSI model)(1). The OSI model is used to characterize and standardize the functions of a communications system in different abstraction layers. Similar communication functions are grouped into logical layers. An instance of a layer provides services to its upper layer instances while receiving services from the layer below. The figure below shows the seven layers used in the OSI model and how two instances in one layer are connected by a horizontal connection in that layer.



0-1 OSI model

Communication paths

A communication system can provide solutions for a number of communication paths. In order to investigate the communication systems we therefore turn to an outline of the possible communication paths in e-navigation, i.e. the ways in which ship and shore can communicate with each other.

In e-navigation, data flows in four directions: Ship $\rightarrow$ shore, shore $\rightarrow$ ship, ship $\rightarrow$ ship and shore $\rightarrow$ shore. For each of the four directions, data can flow in three different ways:

1. **Pull** – Data flows from *x* to client *y.* The flow is initiated by client *y*. This is a client-server communication pattern;

2. **Push-addressed** – Data is pushed from *x* to a single client *y*. e.g. receiving a text message on a mobile phone or sending addressed AIS messages; and

3. **Push-multicast** – Data is pushed from *x* to multiple clients. E.g. Navtex broadcasts and broadcast AIS messages. Multicast (2) is the delivery of information to a group of destinations simultaneously in a single transmission. Broadcast is a special case of multicast where the destination group comprises all possible receivers.

The table below shows the resulting 12 different communication paths.

	Pull	**Push-addressed**	**Push-multicast**
Ship → Shore	1.1 Data pulled from ship on shore initiative.	1.2 Data pushed from ship to single component on shore.	1.3 Data pushed from ship to multiple components on shore.
Shore → Ship	2.1 Data pulled from shore server by ship.	2.2 Data pushed from shore to a single ship.	2.3 Data pushed from shore to multiple ships.
Ship → Ship	3.1 Data pulled from ship on other ships initiative.	3.2 Data pushed from ship to another ship.	3.3 Data pushed from ship to multiple ships.
Shore → Shore	4.1 Data pulled from shore component to other shore component.	4.2 Data pushed from shore component to another shore component.	4.3 Data pushed from shore component to multiple other shore components.

0.1 Communication paths

When choosing a communication system to enable communication paths, two facts in particular are worth mentioning. First, a communication system can often provide more than one solution, e.g. using different protocols. Second, different communication system solutions and solutions within the same communication system often yield solutions with very different characteristics. As an example, both AIS and Internet can be used as communication systems to push data from ship to shore, but the two solutions have very different characteristics with regard to bandwidth and reliability. As regards Internet, different transport layer protocols yield solutions with different characteristics.

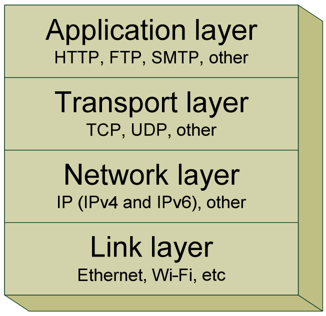
Internet

Internet has been chosen to be a core element of e-navigation. The implications and advantages of using this communication system are described below.

Internet Protocol Suite

Using Internet communication implies using the Internet Protocol Suite (3) which is the set of communications protocols used for the Internet and other similar networks. It is commonly known as TCP/IP. TCP/IP is short for Transmission Control Protocol (TCP) and Internet Protocol (IP) which were the first networking protocols used for Internet communication.

The Internet protocol suite can be described in a simplified OSI model with four layers, cf. the figure below.



0-2 Internet Protocol Suite

Using the Internet Protocol Suite has a number of advantages:

.1 each layer offers widely used and well defined protocols;

.2 the application layer serves as an abstraction of the complexities of the underlying layers;

.3 existing hardware and software components are widely available;

.4 any suitable technology can be used for the link layer. Options e.g. include:

- Ethernet or Wi-Fi (when available, e.g. in harbour);
- Mobile Broadband 3G / 4G;
- Satellite;
- WiMAX; and
- VHF-data.

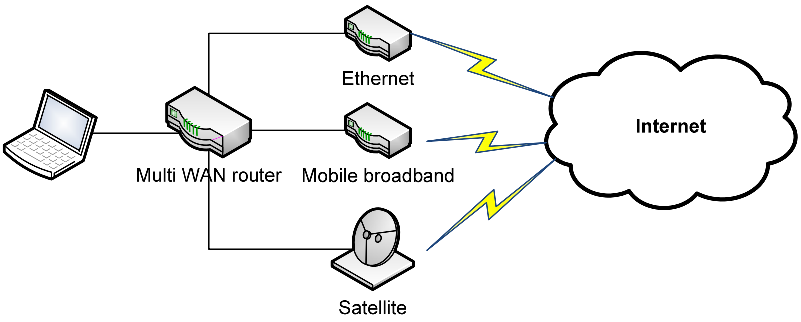
.5 existing application layer protocols have built-in support for authentication, encryption and compression;

.6 The internet protocol suite is easy to integrate with existing Internet based systems; and

.7 The availability and use of Internet on board ships at sea is very likely to increase in future due to the need for e-navigation and the need for information and services from the Internet, e.g. news and social media.

Multi WAN routing

Having multiple link layer solutions allows for so-called Multi WAN routing where the actual internet connection used is the most appropriate in terms of availability, costs and connection requirements (e.g. bandwidth). The figure below depicts this graphically with some link examples.

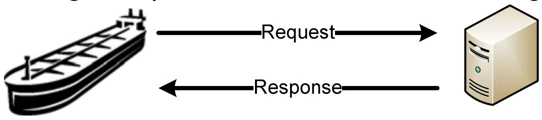


0-3 Multi WAN router with three different Internet connections

The Multi WAN router offers an Internet connection on the inside and hides the complexities of choosing the actual Internet connection on the outside. The router can be configured to the policy used to choose Internet connection and has an application interface to determine which connection is currently used and an application interface to force the use of a certain connection. The ability to determine connection could be important to e-navigation as the properties of the current connection could determine what services are available or desirable. Services requiring high bandwidth may for example not be desirable on a satellite connection. Furthermore the Multi WAN router can be configured with different priorities for different kinds of traffic (quality of service). This is important as it allows for prioritizing e-navigation traffic over less important crew initiated traffic, e.g. email and leisure oriented use of the Internet.

Internet client-server communication architecture

Internet is ideal for a client-server architecture where communication is done using a request-response pattern. A client requests data from a server that responds to the request. This is how the web, email and other common Internet application layer protocols work. Internet is an obvious possible communication system for the *shore → ship pull* communication path. The figure below shows a ship making a request to a server and receiving response.



0-4 Request-response pattern

For the *ship → shore push* communication path Internet is also an obvious choice, as this can be achieved using the client-server architecture. The request contains data to be pushed and the response is a confirmation with some possible additional data. Achieving *ship → shore push-multicast* is to some extent possible by implementing it on the shore side. Received data at one shore component can be shared to other shore components giving the impression that data was pushed to multiple shore components from the ship, cf. e.g. the sharing of AIS data from shore based AIS systems.

Internet limitations

Internet, however, also has limitations. We will have a look at those before turning to the use of Internet for other communication paths.

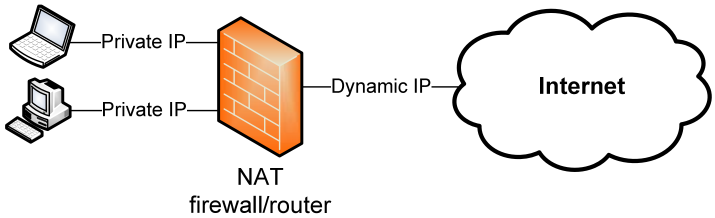
Internet is very suitable for client-server architecture, as servers have fixed IP addresses and in most cases easily memorable DNS (4) names. A client anywhere on the Internet can reach a server if the local network of the client allows it. This is not the case the other way around. A client is rarely reachable from the Internet due to the following limitations:

.1 the Internet service provider (ISP) assigns a dynamic IP address to the client or the router connecting the client to the Internet;

.2 firewalls protect local networks by forbidding incoming connections; and

.3 the IP address space is getting exhausted. A solution has been Network Address Translation (NAT) (5) where a local network uses private IP addresses and shares a public IP address.

The figure below shows a network set-up commonly used in households, companies and on board ships.



0-5 Clients with private IP addresses behind NAT router with dynamic ISP assigned IP

In principle, measures could be taken to make any ship reachable. It would require the following:

- static IP address for all ships or all ship equipment (does not allow for the use of multiple Internet connections);
- a registry of ships and IP numbers/DNS names; and
- router configuration to route incoming traffic to the right equipment.

The above measures are, however, not easily implemented due to the complexity and the administration requirements of the set-up.

The Internet also has limitations as regards the possibility to do broadcasts and multicasts communication between clients and servers. The Internet protocol suite has the transport layer protocol UDP for broadcasting messages, but it only works on local networks and the protocol is fire-and-forget, so no reception acknowledgement exists.

Some of the current limitations may be solved by the new Internet protocol version 6 (IPv6) (6). A complete transition to IPv6 is far away though and IPv4 (the current) will be used in many years to come.

Internet communication architectures for other communication paths

The revisited Table 2.1 below shows by grey shading the communication paths for which Internet is appropriate.

	Pull	Push-addressed	Push-multicast
Ship → Shore	1.1 Data pulled from ship on shore initiative.	1.2 Data pushed from ship to single component on shore.	1.3 Data pushed from ship to multiple components on shore.
Shore → Ship	2.1 Data pulled from shore server by ship.	2.2 Data pushed from shore to a single ship.	2.3 Data pushed from shore to multiple ships.
Ship → Ship	3.1 Data pulled from ship on other ships initiative.	3.2 Data pushed from ship to other ship.	3.3 Data pushed from ship to multiple other ships.
Shore → Shore	4.1 Data pulled from shore component to other shore component.	4.2 Data pushed from shore component to other shore component.	4.3 Data pushed from shore component to multiple other shore components.

0.2 Communication paths for which Internet is especially suitable

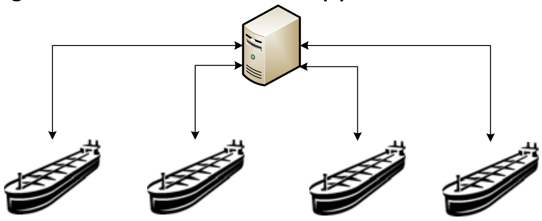
Availability and reliability makes Internet an obvious communication system choice for *shore → shore* communication paths. On shore, clients are often also servers. This allows for the use of client-server architecture. For the push paths, persistent TCP connections can be used. Clients establish a connection and wait for data to be pushed back. This is the pattern used when a VTS system connects to a shore based AIS system.

For the *ship → ship push-multicast* path, Internet is a possibility if the pushed data is distributed between components on the shore side. This may not always be the case. Thus other communication systems may be needed as a solution for this communication path.
For the remaining communication paths, Internet is not an obvious solution. This is not to say that Internet cannot be used. But other architectures may be more appropriate. Such architectures are explored below.

Persistent TCP connections

The transport layer protocol Transmission Control Protocol (TCP) (7) provides reliable and ordered delivery of a stream of bytes between two components. The connection is full-duplex so communication can happen in both directions simultaneously.

Consider that ships maintain a TCP connection to servers on shore. That could be a regional e-navigation server. The shore will be able to push messages to ships both addressed and broadcast. Furthermore, the shore can send a request for data to ships thereby implementing the *ship → shore pull*. The figure below shows this approach.



0-6 Ship maintaining TCP connection to shore server

The approach has some drawbacks that may render it infeasible. Maintaining a TCP connection on a ship may prove difficult for some of the Internet connections available on ships. The connection may often be lost, requiring frequent keep-alive messages to detect and handle connection losses. This will generate traffic on the connection that otherwise was not necessary. The communication equipment would be required to be in a constant ready state. Furthermore, this raises the concern of centralization of service provision and management. Communication is dependent on a number of servers that can be seen as single points of failure. This approach does not scale well beyond the capacity of the servers and its network connections.

On the shore servers, existing application layer protocols cannot be utilized. They must implement a more complex stateful application that has to maintain a potentially large number of simultaneous connections.

Polling

The communication path *shore → ship push,* both addressed and multicast, is without a doubt an important communication path in e-navigation, e.g. for sending maritime safety information. Internet may not offer a simple push solution, but using the technique of polling can mimic a push. In polling the client makes regular requests to a server asking for pending messages. The interval of the polling can be variable and based on the current navigational area of the ship and the type of data being polled.

Polling is a simple solution to accomplish a *push-like* architecture by using the client-server architecture. But it comes at a price that may render it infeasible for some uses:

- data will be received at the ship with a delay up to the polling interval. This delay may be unacceptable for some uses, e.g. for sending time sensitive messages of importance to safety and navigation; and

- polling induces a communication overhead due to polling when no messages are actually pending.

Polling is considered a feasible solution for a number of push oriented e-navigation services.

AIS

The AIS communication system has completely different characteristics than the Internet. By nature, AIS is push oriented as it broadcasts data for everyone within a range to receive. Addressed messages are sent the same way with an intended receiver defined in the message. For addressed messages an acknowledgement message is sent back from the receiver upon reception.

AIS is ideal for broadcasting short messages periodically where the un-reliability of AIS is acceptable. Messages will be re-sent, and the closer you get to the sender, the lower the risk of not receiving the message.

The revisited Table 2.1 below shows by blue shading the communication paths for which AIS is appropriate, given that reliability, bandwidth and range limitations are acceptable. The light blue shading is used for the paths already covered by Internet, and the dark blue shading is used for the paths where Internet does not offer an obvious solution.

	Pull	**Push-addressed**	**Push-multicast**
Ship → Shore	1.1 Data pulled from ship on shore initiative.	1.2 Data pushed from ship to single component on shore.	1.3 Data pushed from ship to multiple components on shore.
Shore → Ship	2.1 Data pulled from shore server by ship.	2.2 Data pushed from shore to a single ship.	2.3 Data pushed from shore to multiple ships.
Ship → Ship	3.1 Data pulled from ship on other ships initiative.	3.2 Data pushed from ship to another ship.	3.3 Data pushed from ship to multiple ships.
Shore → Shore	4.1 Data pulled from shore component to other shore component.	4.2 Data pushed from shore component to another shore component.	4.3 Data pushed from shore component to multiple other shore components.

0.3 Communication paths for which AIS is appropriate. Dark shading is used for paths not already covered well by Internet.

Pulling data is possible by sending a request for data and waiting for a response.

AIS limitations

AIS is only usable for a small number of e-navigation services. It suffers from the following deficiencies:

- very low bandwidth;
- the current VHF channels are getting exhausted;
- it is unreliable and without sophisticated transmission control protocols; and
- no build in security like encryption and authentication.

Desirable future communication systems

There is a need for one or more communication systems in e-navigation to cover the communication paths for which Internet does not offer obvious solutions or only suboptimal solutions, cf. the dark blue shaded cells in Table 2.3. Desirable communication systems should not have the deficiencies of AIS and they should cover as many communication paths as possible.

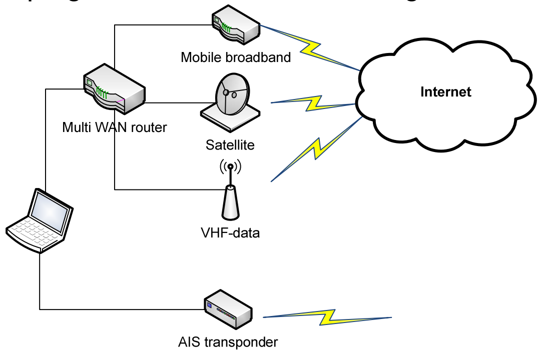
The prototype e-navigation architecture

Data modelling and encoding

Data modeling of the information to be transferred between components was done using UML (8). XML (9) is used to encode data for Internet. Application specific messages is used to encode data for AIS.
It is considered straight forward to define the current e-navigation prototype services using S-100.

Ship infrastructure

The ship infrastructure consists of a software application running on an ordinary PC. The software application is called e-navigation Enhanced INS (ee-INS). The application is open source and based on OpenMap. OpenMap is an open source platform for showing geographical information. A commercial plug-in exists for showing electronic navigational charts. The application has some basic ECDIS navigational features such as AIS and simple route handling. The application implements e-navigation prototype services and is connected to the AIS transponder through the pilot plug and to the Internet through a Multi WAN router.



0-1 Ship infrastructure

Three different Internet connections are used:

1. Mobile broadband from 3;

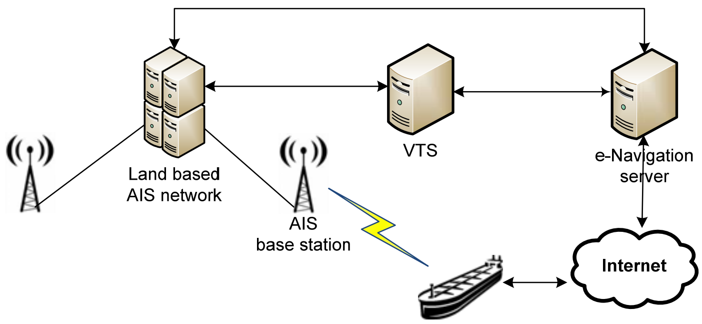
    a. 3G: Up to 32 Mbps download and 5 Mbps upload; and
    b. Failover to EDGE (10) outside 3G coverage: Up to 384 kbps.

2. Satellite – Iridium OpenPort providing up to 128 kbps; and

3. VHF-data from Telenor. Up to 133 kbps.

Shore infrastructure

The shore infrastructure consists of the following components: e-navigation server, VTS system and land-based AIS network. The shore components are connected by the Internet. The e-navigation server delivers request-response based web services to the ship application and the VTS system. The server uses the land based AIS network to receive and send AIS messages. The e-navigation server and the VTS system use the land based AIS network to receive and send AIS messages.



0-2 Shore infrastructure

e-navigation server

The e-navigation server runs applications that implement the prototype services. The applications are accessible through web services and in some cases also through web frontends where data can be presented and entered by users. The applications are dependent on a number of data sources such as metrological and oceanographic prognoses and AIS. Some of these sources are themselves services running on remote servers. Thus, applications implementing services can be dispersed over multiple physical servers and form a service-oriented architecture (SOA) (11).

As web service protocol was chosen XML-RPC (12) over HTTP (13). XML is used to encode remote procedure call (RPC) (14) requests and responses, and HTTP is used as transport mechanism. XML-RPC was preferred over SOAP (15) because it was considered more simple, and because data models for requests and responses can more easily be transformed to XSD (XML Schema Definition) (16) than to SOAP WSDL (17).

To run applications the JBoss application server (18) was chosen. An application server is a software framework that provides an environment in which applications can run. The application server provides a wide variety of services that allow the applications to focus on business logic. Having an application server platform makes it easier to make new applications and to establish connections between applications.

Lessons learned

This section outlines insights derived from the process of implementing the prototype architecture.

Data modeling and encoding

The process of describing a data model for data to be transferred using UML and transforming this into XML Schema Definitions (XSD) was straightforward. Using XML as data encoding induced data overhead due to the markup and the textual representation of numbers in contrast to binary encoding. The use of compression at the HTTP protocol level made it possible to significantly reduce the amount of data to be transferred. Down to 0.04 compression ratios were observed (4% of original size) for larger messages.

Internet communication

Internet request-response proved to be a reliable choice for the *shore → ship pull* and *ship → shore push* paths. Polling was an easy solution for *shore → ship push,* but the delay induced by the polling interval would be unacceptable for some services, e.g. in SAR coordination. The use of polling makes it possible to bundle information in the poll request and achieve periodic reporting. It is also feasible to bundle messages from multiple services in the polling response instead of polling individual services.

The bandwidth of the three Internet links used was sufficient for the prototype services. Service requests were generally completed in no more than 10 seconds. Some service requests are not interactive and performed in the background. For these requests, the time to complete is of less concern.

AIS

AIS proved suitable for periodic broadcast of small messages. For more elaborate communication tasks the limitations of AIS proved to be inhibiting.

It was observed that the use of AIS for communication between ships closely located (< 5 nm) was quite reliable. Using base stations to send and receive messages was less reliable as this approach depended on the distance to the base station and the characteristics of the base station.

There is a clear need for alternative communication systems.

Ship infrastructure

Using the pilot plug on ship bridges turned out to be more challenging than first expected. Quite often the pilot plug was not connected or falsely wired. Furthermore, it was a challenge to connect the pilot plug to the laptop when the two were remotely located. Equipment was used with success that made the pilot plug available over Wi-Fi.

A simple Multi WAN router was used. The failover phase, when the active connection becomes unavailable, had a delay that sometimes was a problem. When a connection becomes unavailable, e.g. mobile broadband, the connection status may jump up and down for a period of time before the connection is finally lost. This may result in frequent connection changes in this period. It is expected that more advanced ship targeted routers will handle this situation better.

Shore infrastructure

Using Internet and standard software components like web server, application server and databases made the shore side implementation quite unproblematic. Having only a single server made it quite clear though, that single points of failure need to be avoided in future. The shore servers need to be resilient and redundant.

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