Maritime communication to support safe navigation

Kay E. Fjørtoft, Beate Kvamstad, & Fritz Bekkadal
MARINTEK e-Maritime, Trondheim, Norway

ABSTRACT: The main objectives of the MarCom project ('Maritime Communications - broadband at sea') are to investigate the main user needs and communication technologies requirements to accommodate those needs within the maritime community. The project will carry out several pilots to demonstrate the usability of terrestrial wireless technologies in combination with, and in some areas instead of satellite communication (SatCom). The major benefit to the maritime users are expected to be reduced costs, increased bandwidth, Quality-of-Service (QoS) and improved communication security and versatility.

The MarCom approach is characterized by combining thorough investigations of present and future user needs through nine scenarios/user cases along with identification of cost-effective communication platforms to match the application requirements being obtained. The MarCom investigations have revealed the bandwidth needs for a set of application groups, and identified the data integrity requirements for each group. Furthermore this paper is addressing the MarCom work with the IMO/IALA e-Navigation strategic initiative in establishing the bandwidth requirements to obtain the major objectives of the e-Navigation concept.

1 INTRODUCTION

MarCom has performed scenario studies in a total of nine different user cases covering nine different focus areas. The case studies have resulted in a total of eight application groups comprising emergency messaging, reporting, technical maintenance, safety and monitoring, infotainment and special purpose applications, as illustrated in Figure 1.
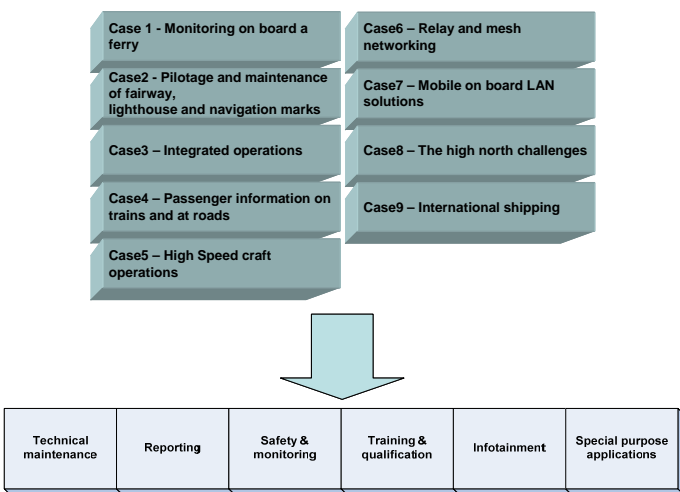

Figure 1 – Application groups resulting from the case studies

A summary of the capacity requirements revealed in the MarCom case analysis is presented in figure 2. The figure shows the bandwidth needs along the ordinate axes and integrity requirements along the abscissa. Integrity is the reliability of the communication channel, i.e is the assurance that the transferred data is consistent and correct, which is reflecting the QoS requirements pertaining to the application group. As can be seen, the requirements vary from a few bytes to be transmitted for operational management below 10 kbps, to data packages of sizes of above 100 Mbytes for special purpose applications (such as e.g for complex offshore operations).
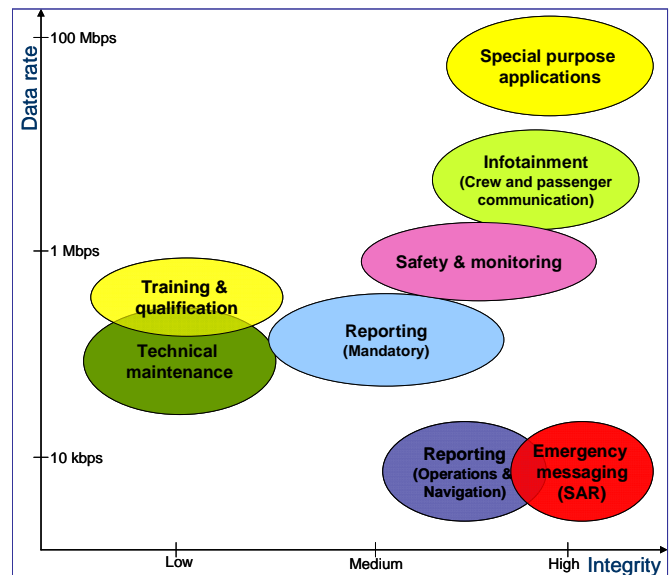

Figure 2 - Capacity versus integrity requirements

One of the important objectives of e-Navigation is to improve the communication between ships, as well as between ship and shore. The International Maritime Organization (IMO) has described e-Navigation as; '*the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment*'.

In MarCom we have studied these objectives by introducing them in the scenarios where both user applications and technology have been addressed.

In the following chapter some of the findings from MarCom in relation to the e-Navigation objectives of IMO are described.

2 MARCOM VERSUS E-NAVIGATION

The following paragraphs are listing the core objectives of the e-Navigation concept defined by the IMO[i]. Within each topic we have listed the MarCom results accordingly along with some conclusions based on the experiences gained from MarCom.

The applications derived from the case studies have been analysed with regards to opportunities and challenges, categorized as:

- *Pain :* What are the problems and challenges within the application groups today?
- *Vision* : How would the applications appear without the existence of the above mentioned pains?
- *Value :* What is the human-related or cost benefit of finding a solution?
- *Power* : Who should be involved to be able to find a solution to the pains?

As an example the '*reporting*' application group has been studied comprising four different reporting sub-groups having been identified as relevant for the MarCom project:

1. Operational Reporting, including route information, cargo information, number of passengers, cash register reserves, deviation reports, travel invoices and HMS reports.
2. Navigational Reporting, including position reports, aids to navigation (AtoN), meteorological and hydrological reporting, and status on fairway objects
3. Technical Reporting, including reports on tank reserves, status reports on technical equipment, reporting between systems and sensors, and cargo reporting
4. Mandatory Reporting, including reporting to port and government, ISPS, classification, and environmental monitoring

Group 1 and 2, operational and navigational reporting requires higher integrity than the two others since it is critical to safe operations.

Examples on different observations have been described in detail, such as for example the *cash register reserves* in group *operational reporting,* where they have been studied in accordance with the four abovementioned issues; a *pain* observation is that the cash register services have to be online to validate the different cards used in a transaction. The *visions* is that the there will be no transaction and verification delay on the different credit cards used as payment. *Value* is that better QoS provided by a high-speed network gives correct validation of a money transaction and can thereby validate potential money transfer without account settlement. Finally the *power* to handle these challenges can comprise the providers of infrastructure (data transmission, service providers, LAN solutions, terrestrial to satellite solutions), the cash register software developers, and the end users.

For each group we have analysed the requirements from a technological and human (user) point of view. This has given us the understanding of future applications and technological needs that have been defining the requirements of communication solutions.

In the MarCom project we have then analysing the findings with reference to the IMO e-Navigation objectives of being listed in the following paragraphs.
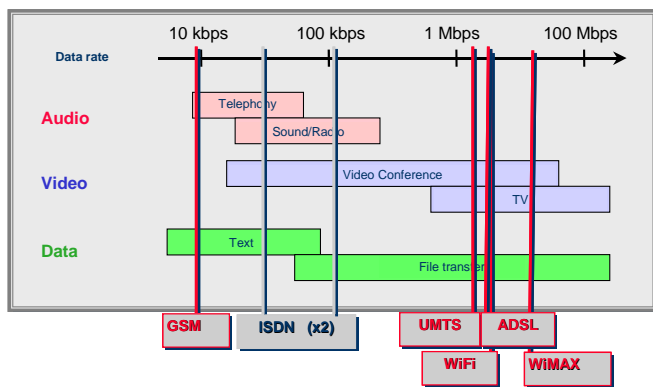
2.1 IMO e-Navigation objective: '*Facilitate communications, including data exchange, among ship to ship, ship to shore, shore to ship, shore to shore and other users*'

The need for transfer of data from a ship to shore is considerable. Previous studies have shown examples that a ship sailing from a foreign port has to send mandatory information to governmental bodies more than 40 times during a voyage[ii]. In addition is the commercial reporting and monitoring (to cargo owners or system equipment providers, with information about technical status on equipment as well as on the cargo), and the communication between the shipping company and the ship.

In MarCom we have mainly focused the communication between ships and shore, but some communication onboard the ship has also been paid attention to.

The upper part of Figure 3 shows some telecom services and bandwidth requirements for terrestrial systems that have been studied in view of the applications described, while the matrix in the bottom part is pertaining to services offered by different SatCom systems to accommodate these capacity requirements.

However, since MarCom's foremost technological objective is to extend the coverage and range at sea for both in-use and novel terrestrial wireless systems and technologies, these solutions have been given priority to SatComs.

Figure 3 diagram labels:

Data rate: 10 kbps | 100 kbps | 1 Mbps | 100 Mbps

Audio — Telephony; Sound/Radio
Video — Video Conference; TV
Data — Text; File transfer

GSM | ISDN (x2) | UMTS | ADSL | WiFi | WiMAX

	Inmarsat-A	Inmarsat-B	Inmarsat-mini-M	Inmarsat-C	Inmarsat-mini-C	Inmarsat Fleet 77	Inmarsat Fleet 55	Inmarsat Fleet 33	Inmarsat GAN	Inmarsat RBGAN	Iridium	VSAT Services
Voice	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes		Yes	Yes
Telex	Yes	Yes	No	Yes	Yes	No	No	No	No		No	Yes
Fax	Up to 9.6 kbit/s	9.6 kbit/s	2.4 kbit/s	Mobile to Fixed only	Mobile to Fixed only	9.6 kbit/s	9.6 kbit/s	9.6 kbit/s	2.4 kbit/s	No	No	Yes
Data	Up to 9.6 kbit/s	9.6 kbit/s or with HSD 64/56 kbit/s (ISDN)	2.4 kbit/s	600 bit/s	600 bit/s	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	9.6 kbit/s and 28.8 kbit/s MPDS from Fleet 33	64/56 kbit/s ISDN and 64 kbit/s MPDS (packet switched)	Up to 144 kbit/s based on IP	2.4 kbit/s	4.8 kb up to 2 Mb Two way 4.8 kb up to 34 Mb Broadcast
Internet E-mail	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
Communications	Real-time	Real-time	Real-time	Store & Forward	Store & Forward	Real-time	Real-time	Real-time	Real-time	High speed access	Real-time	Real-time
Transmission	Analogue	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital
Terminal weight	50 kg	25 kg	2.5 kg	5 kg	1.1 kg	5 kg	3 kg	1.5 kg	4 kg	1.6 kg	0.5 kg	
Antenna type	Directional	Directional	Directional	Omni-directional	Omni-directional	Directional	Directional	Directional	Directional	Omni-directional	Omni-directional	Directional
Coverage	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Spot beams in AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Global voice, spot beam data in AOR-E/W, IOR, POR	Global voice, spot beam data in AOR-E/W, IOR, POR	AOR-E/W, IOR, POR	Thuraya satellite coverage (North/Central Africa, Middle East & Europe)	Global, incl. the poles	AOR, IOR, POR
GMDSS approved	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No

AOR: Atlantic Ocean Region
IOR: Indian Ocean Region
POR: Pacific Ocean Region

Figure 3 Basic telecom services and bandwidth requirements

One of the user cases, *relay and mesh networking*, has taken this a step further within the communication aspect of terrestrial systems, having studied solutions for mesh networking, i.e. networks where the available nodes in an area can be used to relay data, and thus increase the communication range and area coverage. This case comprises technology demonstrations aiming at coverage area extension and flexibility enhancement by applying a system enabling mobile stations to communicate with a base station through intermediate relay units. The focus is on handover challenges, as well as the mixture of fixed and mobile nodes interconnected via wireless links to form a multi-hop ad-hoc network amongst ships, marine beacons and buoys.

The experiences gained in MarCom have been that we must utilize different communication channels and we need to be able to switch between the different channels. The handover mechanisms between the channels as well as between the base stations must be developed such that the user feel they have a secured link without need of new identification when switching sources or base stations. It would also be beneficial to combine up- and downlinks from different systems, an example being that one channel can be used for uplink, e.g. UMTS, and another for downlink, e.g.. WiMAX. It is also important to prioritise those application groups that need high integrity to ensure safe transmission of data. This requirements lead to the need for an intelligent router on the ship to poll and switch between

the pertinent systems, which is part of the MarCom work.

2.2 IMO e-Navigation objective: *'Facilitate safe and secure navigation of vessels having regard to hydrographic, meteorological and navigational information and risks'*.

These e-Navigation requirements have been linked to the reporting application group in Mar-Com. There are different needs on the update frequency of data, from time-critical data for navigational purposes like updates on the traffic situation in the ship's vicinity, to data used for a planning purpose that not are time-critical. Meteorological data is mostly needed on a planning level and can be used within a longer timeframe. However, the information to nautical operators, the status on navigational objects like lighthouses and buoys or other navigational marks, has been placed in the "reporting operations and navigation" application group, where the data integrity is high.

The MarCom studies have concluded that the bandwidth needed for meteorological and hydrographic data is high, but the service required is not time-critical. Regarding information on dynamic objects such as other ships in a fairway, the updating frequency needs to be higher. The information in this group must in any case be regarded as a substitute to a safe navigational operation, and thus merely as a substitute to the navigational personnel.

2.3 IMO e-Navigation objective: *'Facilitate vessel traffic observation and management from shore/coastal facilities, where appropriate'*.

One of the case studies in MarCom is pilotage and maintenance of fairways that has been lead by the Norwegian Coastal Administration. The focus has been to provide the sailors with real-time navigational information, on e.g. the status of navigational objects. The work has been done in two steps; firstly collecting the status from the Coastal Administration (technical maintenances of the navigation objects), and subsequently sending the information to the ships' navigators.

Based on the studies in MarCom, it can be shown that the bandwidth needed for monitoring of a ship position by use of AIS is low. Another conclusion is that one of the communication challenges is to transfer data from e.g. VTS centre ashore to the ship. The integrity classification on the data is high since it is used for navigational purposes.

2.4 IMO e-Navigation objective: '*Provide opportunities for improving the efficiency of transport and logistics*'.

One of the major challenges in ship operations is to make the correct decisions at the correct time. It is a serious problem having to rely on old or maybe wrong data when an operational planning is done. The focus on the problem is highly prioritised in the oil and gas industry where Integrated Operations (IO) should allegedly be one of the beneficial mechanisms in providing efficient and controlled logistical planning processes. It is stated by The Norwegian Oil Industry Association (OLF) [iii] that there is a potential for saving yearly up to 300 billion NOK if the use of Integrated Operations can be fully developed[iv] in the Norwegian oil sector. Integrated Operations focuses on how to share data and information between the involved partners to be able to have the same overview, and thereby being in a better position to make, appropriate decisions for correct operations.

Integrated Operations will be one of the demonstration pilots in MarCom, and we are aiming at testing out some of the applications that have been identified in the case studies, where the focus will be on utilizing different technological communication solutions. The bandwidths needed for Integrated Operations are very high due to the use of pictures, sound and video being essential for its success. This requires communication technologies that can handle data rates at least up to around 20 Mbps.

MarCom will test different communication solutions and perform radio channel sounding measurements at appropriate frequencies in some sectors in order to identify capacity and range performance. One of the challenges regarding maritime communication is the radio propagation over sea, low elevation angles, and the roll and pitch movements of both a base station placed offshore, as well as at the mobile station on e.g. a ship. In MarCom we will perform studies on these topics and will real on-site measurements on the pertinent frequencies for wireless systems. We expect the availability of higher bandwidths to provide more efficient operations regarding the transport segment.

2.5 IMO e-Navigation objective: '*Support the effective operation of contingency response, and search and rescue services*'.

There are no specific applications in MarCom directly addressing this topic regarding contingency planning and response, but some defined cases have addressed the topic on safety and monitoring as well as emergency reporting. One of the cases has focused upon the relay and mesh networking to be used in a search and rescue operation. The idea is to build an ad-hoc network around the accident loca-

tion to support data transmission in an operation. Another case has focused on presenting real status of the fairway objects to be used both for maintenance planning as well as data transfer to ships sailing in a fairway.

Based on the comments and experiences from the case studies in MarCom we can see that one of the problems in an emergency situation is the enormous pressure from media and outsiders to get information from a catastrophic situation, like a ship accident. This requires a lot of bandwidth to transfer data, which is in some cases taken from the available channels used by the rescue team or from those that are handling the accident directly. MarCom will strongly recommend that applications used in search and rescue (SAR) operations must be prioritized, preferably via an exclusively dedicated channel, such that the best channel and bandwidth available can be used by those needing it most.

2.6 IMO e-navigation objectives: '*Demonstrate defined levels of accuracy, integrity and continuity appropriate to safety-critical system*'.

The challenge having been addressed in MarCom is to define which application groups require high integrity that must be absolutely reliable with regards to safety-critical operations. On the opposite we have the training and qualification applications that are not critical to safe operations, and are classified as nice-to-have, and hence have low integrity requirements. The application groups defined in the project will be further developed and demonstrated in the pilots.

The e-Navigation objectives described above will be of high importance to the MarCom project. We are demonstrating effective operation of contingency response, and efficient SAR services are facilitated by technological possibilities for communication. In MarCom we have defined this as most critical application group, and thus subject to a very high integrity level.

2.7 IMO e-navigation objectives: '*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*'.

One of the problems with presenting critical information in an unwanted situation is that this information can be used juridical against the source of it. For example if the captain or the safety officer on a ship are guiding the passengers in a non-optimum direction during an emergency situation, this can be used against them at a later stage. Similar situations can also arise in provision of navigational information because presentation of wrong data is more critical than no data provided. Therefore a validation

of the navigational data must be done which also means a transfer delay due to the validation time. Navigational information can be received from many sources, such as onboard systems, hydrographical and meteorological providers, or from the traffic stations that provides fairway information to be used for navigational purposes.

Based on the experiences from the MarCom scenarios we can see that the navigators in some settings have too much information and must therefore be able to filter it such that only significant information is displayed. Sea transport is global and the providers of data are dissimilar, depending on the position of the ship. This requires international standards to provide data in a unified format to minimize the risk of confusions and avoid misunderstandings.

2.8 IMO e-Navigation objectives: *'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'*.

The above issue has been focused in the Integrated Operation case study, and will become a part of one of the MarCom pilots. The idea is to share the same information between the operational planning centre, the vessels involved, the offshore installations, and eventually the system equipment providers. The objective is to convey the information as close to the decision makers as possible, in real time, which will result in an easier decision line between those involved in the execution of a decision and those planning the operation. By having better means to monitor the equipment status and condition, it will be possible to avoid unexpected situations with a real-time status of the equipment.

MarCom studies have shown that there might be several different communication channels used in an operation. Needs for a solutions such as an intelligent router that can be used to select proper channels to transfer data based on availability are obvious. Another observation is that the presentation of the information should be done in a standardised way to avoid misunderstanding between the users. If all workers being physically involved in an operation also are involved when the decisions are made it seems most likely that correct decisions are reached upon.

2.9 IMO e-Navigation objectives: *'Incorporate training and familiarization requirements for the users throughout the development and implementation process'*.

This issue is very important regarding a successful implementation of a system. The desired situation when introducing a new system is that the users have a good understanding on the possibilities of the system, as well as having a feeling that the system is beneficial for them. This will again result in a more familiarization to the system and the user threshold will be lower.

Another observation is that the majority of maritime workers is getting older and will retire in a few years time. A new generation sailors are about to enter the sector, and with them also requirements on higher bandwidth, since they are used to be surfing the Internet and being more integrated in the society ashore. One challenge in the change of working generations is to preserve the knowledge from one generation to another. This can be done by training and courses offered to the new generation, but another viable solution is to establish an operational centre that both can monitor equipment etc. along being utilized to give expert advices about the ship and its condition. In order to manage such a system an online ship-shore communication channel providing satisfactory capacity to transfer data being used in a decision process is required.

Training applications and video conferences need high data rates, likely more than 2 Mbps. In MarCom we have particularly studied the emerging WiMAX technologies that provide enough bandwidth to support transfer of video and pictures between ship and shore sites. Technologies that only provide low capacity channels supporting but transfer of small data packages are not suitable for this purpose.

2.10 IMO e-Navigation objectives: *'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 be scalable, to facilitate use by all potential maritime users'*.

Use of standards and routines with a global perspective is important in the maritime industry, since many of the users are sailing long distances and crossing many borders with different jurisdictional responsible communities. Critical systems used for navigational purposes should therefore be developed to enable operations on a global level and preferably be presented in a common way independent of the data providers. It is also beneficial to have common operational procedures to avoid conflicts and misunderstandings, especially in a critical situation.

Regarding deployment of communication systems there are different aspects that do not make all of them possible to be used on a global basis. The development of new maritime communication technologies is presently not market-driven because of the initial number of users being limited. Deploying wireless systems with high bandwidth to cover a wide area is also quite expensive, and must be per-

formed not only to reach everyone everywhere, but also from needs to support safe operations in harsh environments. The approach must thus rather be to state that there is a requirement for access to communications, and that suitable systems must be implemented. Based on experience when the systems are available the traffic will grow, like when the Inmarsat system was implemented the most important consideration was "Safety of Life at Sea" and IMO was an active participant in the establishment. Later it appeared that the Inmarsat system became a gold mine for equipment manufacturers, system operators and the service providers, and it became an indispensable service for the users.

3 CHALLENGES AND POSSIBLE SOLUTIONS

The challenges in MarCom have been to identify user requirements to both applications and technology. The development of new maritime communication technologies is presently not market-driven because of the initial number of users being limited. The maritime sector has a relatively low number of users, and thus not sufficiently attractive to commercial actors. The focus could rather be on some sectors having the capability to finance deployments of a communicational infrastructure. Another observation is that the maritime sector is of global nature, and it is not easy to harmonize licensing of available communication frequencies, since there are many commercial interests involved. Each country has the authority to manage their frequency resources, and the harmonization between countries is not satisfactory regarding frequencies for maritime use. Solutions like 'intelligent toolboxes'/'smart routers' and reconfigurable radio's to switch between channels based on availability and bandwidth requirements are therefore of high importance to maritime users operating globally. At the same time safety critical applications must be provided with dedicated radio channels being globally applicable and capable of supporting applications with high integrity and availability requirements.

Another challenge strongly connected to the requirements regarding a globally harmonized solution is the poor developed communication infrastructure at high latitudes, i.e. beyond about 70°N. The maritime traffic is expected to increase significantly in these areas in a few years time due to the ice meltdown in the Arctic waters. Possible solutions to this challenge are investigated in the MarSafe project[v].

One objective in the MarCom project is to enable provision of high bandwidth to specific areas, and the Mesh networking methods being investigated are attractive to maritime users in areas where a new network can be deployed to accommodate those needing bandwidth for special operations. By establishing such ad-hoc networks the coverage area is extended, since the signal can be transferred by using each other as relay units in a network with multi-hop capabilities. This is beneficial in parts of North Sea and the Norwegian Sea, where e.g. offshore oil installations have fiber connections, and may therefore be used to accommodate base stations in a mesh network. Preliminary investigations have indicated possible coverage ranging to about 20 nm (~37 km) from an off shore WiMAX base station operating at 2.3 GHz, a rather encouraging result.

REFERENCES

[1] MarCom D2.1:" Methodology for description of cases and user requirements", Draft version 0.7, 24.10.2007

[2] Bekkadal, F :MarCom D4.1: 'Maritime Communication Technologies', *MARINTEK Report, V1.0, 2009-01-05.*

[3] MarCom D3.1: "Case descriptions and user requirements", Draft version 01, 30.10.2008

[4] Rødseth, Ørnulf Jan & Kvamstad, Beate: "The role of communication technology in e-Navigation", *Draft MARINTEK Report, V07, 2008-06-20*

[5] Grythe, K., Gutteberg, O., Jensen, I.A., Røste, T., Swendgaard, H.E.:'Satellittkommunikasjon til nordområdene - en behovsundersøkelse', *SINTEF Rapport, prosj.nr.: 90F252, 2008-02-28*

[6] Jaya Shankar s/o Pathmasuntharam: " High Speed Maritime Ship-to-Ship/Shore Mesh Networks", *MarCom Summit #1, Trondheim, 8th-9th April 2008*

[7] Marchenko, Aleksey V.: 'A study on ice types and movements and its influence on ships', January 2009

[8] 'A case study from an emergency operation in the Arctic Seas'; Beate Kvamstad, Kay E. Fjørtoft, Fritz Bekkadal, MARINTEK e-Maritime, Trondheim, Norway, Aleksey Marchenko, University of Svalbard, Jon Leon Ervik, The Norwegian Coastal Administration

[9] Fritz Bekkadal: "Novel Maritime Communication Technologies", January 2009

---

[i] IMO - Sub-Committee on Safety of Navigation (NAV), 53rd session: 23-27 July 2007

[ii] Source; The EU-project MarNIS and the Norwegian project VITSAR

[iii] OLF The Norwegian Oil Industry Association

[iv] http://www.olf.no/aktuelt/muligheter-for-300-milliarder-kroner-i-oekt-verdiskapning-article1732-223.html