Broadband Communication Solutions for Maritime ITSs:

Wider and Faster Deployment of New e-Navigation Services

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***Abstract*—In its initial part, the paper presents an overview of popular technologies and systems currently developed or employed in maritime communication. These solutions are used to provide both ship-to-ship and ship-to-shore communication for the purpose of supporting specific services, often dedicated to maritime safety and e-navigation. Utility of such communication systems have been thoroughly verified over the years and their strengths and limitations are also widely known. The later include relatively low maximum throughput and/or high cost of both deployment and operation, caused by the requirement of long communication range and high reliability in difficult propagation conditions. Based on the above overview, the subsequent part of the paper presents preliminary results of research conducted at the Computer Communications Department, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology within the netBaltic project. The project's objective is to create a maritime communication system, able to transparently utilize various transmission technologies to form a multihop network structure and thus provide maritime vessels with Internet Protocol-based communication capabilities in diverse set of conditions and areas. For this purpose a combination of mobility management, mesh and delay tolerant network mechanisms is employed, allowing deployment of a wide range of user-level services, starting with general purpose Internet access, through navigation/weather charts distribution and ending with varied e-navigation functionalities.**

Keywords*—*Maritime systems – an overview, single hop and mesh networks, satellite solutions, IMO manadated systems, AIS, e-navigation, security, new services, netBaltic, architecture, self-organization, inteligent switching, heterogenity

I. INTRODUCTION

Many organizations and research working groups, including among others IEEE (Institute of Electrical and Electronics Engineers), ITU (International Telecommunication Union), ETSI (European Telecommunications Standards Institute) as well as IMO (International Maritime Organization), EUAR (European Union Agency for Railways) and IATA (International Air Transport Association) are currently working towards improvements in communication of different types of vehicles (cars, trains, planes and ships) and upgrading utilities and services offered to their crews and passengers travelling all over the world (including for example entertainment and broadband access to global networks for everybody). With the most important requirements being ubiquity of access, security, reliability and a set of user-oriented services possible to deploy, the modern Intelligent Transportation Systems (ITS) require secure, resilient and efficient network communication capabilities (often employing heterogeneous solutions), robust network integration solutions and comprehensive application support. While such requirements can be considered universal for ITS systems in general, their practical implementation often varies depending on a particular environment (road, rail, air, sea, etc.).

Without doubt, much research is directed towards elaboration and standardization of intelligent transportation systems for vehicles moving over roads. There are many projects carried out in this area by different organizations and countries. ITS solutions improving safety in road communication Vehicle 2 Vehicle (V2V/C2C) and/or Vehicle 2 Infrastructure (V2I/C2I) include, among others: Dedicated Short-Range Communication (DSRC) – Wireless Access in Vehicular Environment (WAVE) - solution combining IEEE 802.11p and IEEE 1906 standards (prepared with a strong support from Intelligent System of Transportation in America - ITSA), Communications Access for Land Mobiles (CALM) – the ISO ITS proposal, complementary with ETSI standardization, as well as Japanese solutions presented by e.g., Association of Radio Industries and Business (ARIB) [1-5]. All these systems offer similar functionalities and services. They differ with each other by details of their architectures.

A lot of research and standardization works is also conducted in the area of railway systems. The leading organizations in Europe are the European Union Agency for Railways (EUAR) and the European Rail Research Advisory Council (ERRAC). The European Union Agency for Railways (formerly ERA - European Railway Agency) is the agency of the European Union (EU) that sets mandatory requirements for European railways and manufacturers in the form of Technical Specifications for Interoperability, which apply to the Trans-European Rail system that includes the European Rail Traffic Management System (ERTMS) together with its components the European Train Control System (ETCS) and GSM for Railways (GSM-R).

As airlines became one of essential players in transportation of passengers and goods on long distances, thus creating a growing demand for efficient communication systems able to support mobile users over large areas, Broadband Mobile Satellite Communication systems gained significant importance, improving the flights security and convenience of airline passengers [6]. Satellite-based technology solutions and network architectures able to provide bi-directional connectivity at tens to hundreds of Mb/s have been developed and deployed. A good example of such a system is Inmarsat, dedicated for aeronautical deployment [7] providing services customized for this environment. However, other satellite systems e.g., Iridium [8] also offer specialized aeronautical services.

In case of maritime communication we observe growing interest in deployment of multitask satellite-based solutions and development of new maritime specific systems intended for improvements in safety of e-navigation. Analysis of different types of currently used maritime communication systems leads to a conclusion that neither global and still very expensive satellite systems nor cheaper, but shorter ranged transmission technologies [9-14] can, on their own, fully meet the today's expectations and quality requirements formulated for broadband maritime systems [13]. This lack of reliable solutions, offering high throughput and ubiquitous availability of coverage to a wide audience at a relatively low price is one of the main barriers in a widespread implementation of e-navigation initiatives [17-18]. Systems using terrestrial communications are mostly narrow-band (service specific, sub-1 GHz technologies) or offer too short ranges at sea (on-shore mobile data transmission systems, such as GSM, UMTS or LTE) [14-16]. Satellite communications systems are, in turn, too expensive for the universal deployment necessary for fulfillment of the majority of e-navigation goals.

The paper is organized as follows. First, in Section II an overview of different IMO mandated long range radiocommunication systems, together with a brief presentation of services offered by satellite systems is given. Next, in Section III example broadband maritime communication initiatives are presented. Finally, in Section IV, based on above overviews objectives and preliminary results of the netBaltic project are given.

II. Maritime communication systems

Access to information essential for safety and efficient navigation on the sea and ensuring the ability of continuous data exchange with the outside world at a high level of quality (QoS) with Mb/s speeds typical for modern, wireless terrestrial networks, is becoming increasingly important for maritime vessels. While critical, safety-related services have been designed and standardized to be reliably maintained using vary low throughput data channels, supplementary services, such as download of digital navigation maps, frequent update of weather maps, automatic route optimization or various remote monitoring and maintenance services require significantly more efficient communication capabilities.

In 2005 the IMO [13] defined the new concept of e-navigation as „a harmonized process of collection, integration, exchange, presentation and analysis of maritime information using electronic devices on board and / or ashore to support the navigation and related services to ensure the safety at sea and protection of the marine environment.„. In practice, this means the integration of existing and creation of new electronic solutions, information technology, telecommunications and digital services to support the widely understood process of maritime navigation. The main objective of the implementation of e-navigation is to increase the safety and efficiency of maritime transport [17]. In 2014 IMO has developed a strategic plan for the implementation of e-navigation (E-navigation Strategy Implementation Plan - SIP) [18], which sets out the basic list of tasks to be implemented in order to effectively implement the objectives of e-navigation.

These tasks include:

1. increase the convenience of navigators on the navigation bridge,
2. the introduction of automated generation and sending standardized reports
3. to increase the reliability and resistance to destruction or damage to equipment and navigation data,
4. integration of information received through communication devices, and graphical presentation of this information,
5. improving communication within the portfolio of vessel traffic services VTS.

Implementation of these new services in maritime environment becomes a real challenge for both standardization bodies and researcher all over the world.

In this section a short overview of currently employed maritime communication systems, possibly capable of supporting diverse ITS usage scenarios is being presented.

A. *HF/VHF Systems*

An analysis of currently used, dedicated HF/VHF maritime radio communication systems such as Global Maritime Distress Safety System (GMDSS) [19], Automatic Identification System (AIS) [20] or NAVigational TelEX [21] and their offered communication parameters (coverage and availability vs. the quality of transmission) shows that the possibility of their successful employment to support throughput intensive ITS applications is very limited.

Existing HF/VHF technologies, although they offer long link ranges, are unreliable and their bandwidth are very constrained. Cellular systems' base stations are not typically planned for offshore usage, thus their coverage over sea areas is limited. New transmission technologies, such as a highly promising VHF Data Exchange System (VDES) system (expanding e.g., AIS services) are still in the phase of their standardization and development [22-25].

B. *Evolution of HF/VHF – standardization of VHF Data Exchange System (VDES)*

VHF Data Exchange System (VDES) is a technological concept developed by the IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities*)* e-NAV Committee and now widely discussed at ITU, IMO and other organizations. VDES was originally developed to address emerging indications of overload of VHF Data Link (VDL) of AIS and simultaneously enabling a wider and seamless data exchange for the maritime community. VDES is expected to facilitate numerous applications for safety and security of navigation, protection of marine environment, efficiency of shipping and others [22-25].

Currently, AIS is universally recognized and accepted as an important tool for safety of navigation, being a carriage requirement for SOLAS (Safety of Life at Sea) vessels

(Class-A). However, because of its effective and useful technology, the use of AIS has been expanded to vessels not complied with the carriage requirement (Class-B) and other applications such as Aids to Navigation (AtoN), Application Specific Messages (ASM), Search and Rescue Transmitter (SART), Man Over-Board unit (MOB) and EPIRB-AIS (Emergency Position-Indicating Radio Beacon**)**. This expansion of AIS technology has caused significant increase in VHF Data Link's (VDL) load utilized by the system, which has become an active concern for both IMO and ITU.

Simultaneously, because of increasing demand of radio spectrum resources to be used for digital communication such as mobile phone and data, ITU requested more efficient and effective methods of utilizing the available radio spectrum to be developed. In 2009, ITU issued Recommendation ITU-R M.1842-1 "Characteristics of VHF radio systems and equipment for the exchange of data and electronic mail in the maritime mobile service RR Appendix 18 channels". This technique will provide higher data rates (up to 32 times that of the present AIS) and will become a core element of VDES. Furthermore the VDES network protocol will be optimized for data communication, so that each VDES message is transmitted with a very high confidence of successful reception. Consequently VDES will allow more efficient and effective use of marine VHF spectrum, with specific emphasis on digital data transfer.

IMO is still developing an e-navigation strategy implementation plan, conducting simultaneously, a review and modernization of GMDSS with a target completion in 2017. In the discussion of both matters, one of the common key elements is exchange of information, possibly able to be accomplished by digital data exchange, which in turn, can be achieved using a whole multitude of commercially available data links. However, their global availability and interoperability is an issue. Since VDES gives an opportunity for a globally interoperable capability of significantly higher speed and larger volume data exchange than AIS or DSC (Digital Selective Calling), and potentially with worldwide coverage, VDES can become one of core facilitating elements for both implementation of e-navigation and modernization of GMDSS. It is anticipated that VDES may be implemented in two parts, terrestrial VDES and satellite VDES. Some radio manufactures have already started to develop the prototype transceiver that has capability of VHF digital data exchange (VDE) function which is defined by Recommendation ITU-R M.1842-1. Although such VDE transceiver has only limited capability of VDES, the core technology of the VDE transceiver will be incorporated into the first implementation of VDES [21-25].

The transmssion capabilities descrbed above should allow the VDES to integrate functions of AIS, ASM and VDE. Communication channels for these functions have been fully specified for terrestial transmission and reception and in part for satellite communications.

Moreover, since VDES is designed to provide a much higher data exchange capabilities than AIS, while retaining its worldwide compatibility, various additional functionalities can be considered. The robustness of radio link types allowed by VDES specification has been illustrated in Fig. 1.

Fig. 1. also provides a summary of the proposed assignment of VHF channels to different communication services within VDES specification.

All of the above characteristics make VDES a solution crucial for the future introduction of e-navigation. Its capability of high speed digital data exchange with potential for a worldwide interoperability may allow implementation of new, universally compatible e-navigation services and modernization of GMDSS.

Due to the high complexity of the integration of both terrestrial and satellite aspect of the VDES, together with the need to ensure that VDES will not interfere with AIS, a tremendous number of studies is in progress. Numerous meetings are organized to validate and confirm various options of a channel plan.

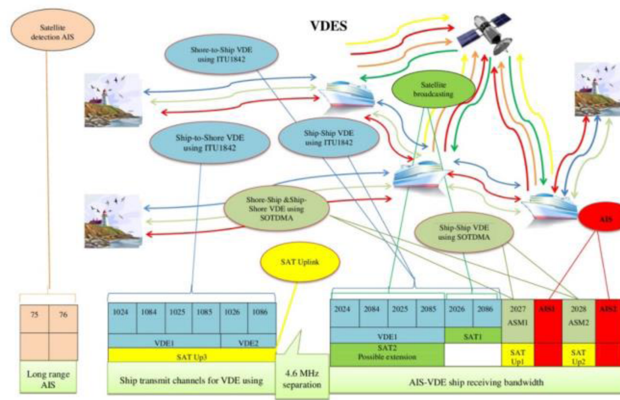

Fig. 1. VDES radio links

C Satellite systems

With relatively cost-effective HF/VHF systems, currently available, providing however very limited (low throughput and medium range) digital data exchange capabilities, satellite communication solutions remain a viable, but still expensive alternative.

Satellite systems currently used for purposes of digital maritime communication, such as Inmarsat, Iridium, Globalstar, SES (ASTRA2Connect Maritime Broadband), Intelsat (International Telecommunication Satellite consortium*)* and wide selection of VSAT (Very Small Aperture Terminals) offer a significant advantage in form of a global coverage, but their offered throughput does not exceed several Mb/s while most often being limited to a fraction of a single Mb/s. Moreover, such systems are generally too expensive for mass data transmission and often unaffordable for owners of smaller vessels.

1) IRIDIUM

In a LEO class of satellite systems a leading position occupies Iridium with 66 satellites. Iridium is the world's largest commercial satellite constellation. This global mobile satellite communications system offers voice and data services addressed to many global customers [26].

The data may be routed directly to the ground network from the satellite. The ground network comprises two major elements: system control segment and gateways.

In addition to the direct links to the ground, each Iridium satellite is linked to four other satellites in the constellation - two other satellites in the same orbit - these will be the ones either side of it, and it also links to two other satellites in adjacent orbits. These links provide a network in space which allows data to be routed between satellites without having to return to the ground from each satellite (see ISL – Inter Satellites Link in Fig. 2). Messages may even be routed across several satellites before reaching the ground.

From the very beginning Iridium offered services dedicated for maritime environments, mainly used by in-situ Ocean and meteorological platforms. In 2013 the system provided global, reliable communications (including GMDSS services) for nearly all segments of the maritime industry, consisting of more than 50,000 subscribers worldwide and 15,000 SOLAS class vessels. Iridium was also used to provide maritime safety and regulatory communications, like LRIT (Long-Range Identification and Tracking) and VMS (Vessel Monitoring Systems).

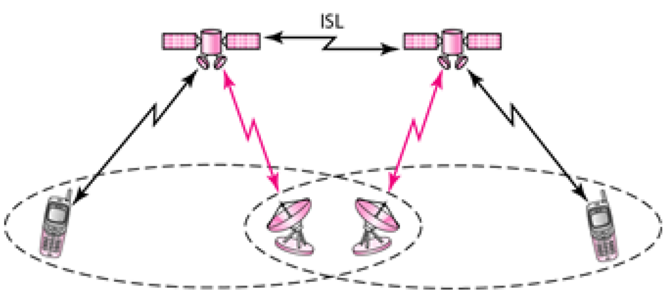

Fig. 2. Example illustration of Iridium - LEO satellite system [27]

The Iridium system offers a number of important maritime services, including:

- A telephony service to be used in ship-to-shore and ship-to-ship communication scenarios,
- A data service, capable of supporting a bi-directional ship-to-shore data transmission,
- A global, one-way data service useful for distribution of Maritime Safety Information (MSI).

One of more advanced Iridium services is still Pilot which replaced the OpenPort service. Iridium Pilot offers an up to 128 kbps bidirectional broadband service.
Currently Iridium is moving to the Iridium NEXT solution.

2) GLOBALSTAR

In February 2013 deployment of the second generation constellation of Globalstar system, consisting of 24 satellites, was completed, with the launch of the final six satellites. These second-generation satellites are expected to provide Globalstar customers with satellite voice and data services until at least 2025 [28] with the constellation counting the total of 48 satellites.

The Globalstar satellites are relatively simple as they utilize a “bent-pipe” architecture. This means that the uplink signal is received, amplified, translated to a downlink frequency, amplified again, and directed towards the earth using a high-gain antenna. A bent-pipe satellite does not demodulate and decode the signal. A gateway station on the ground is necessary to control the satellite and route traffic to and from the satellite and to the Internet.

Many land based and maritime industries benefit from Globalstar with increased productivity from remote areas beyond cellular and landline service. Quite recently, in 2015 the Globalstar GSP-1700 – one of the smallest and lightest satellite phones on the market has appeared. It boasts both the high voice quality and data speeds. Additionally, paired with additional equipment, customers of Globalstar can use their existing access devices to send and receive emails over the Globalstar satellite network [29].

3) INMARSAT

Inmarsat [30] operates a fleet of geostationary satellites (GEO) that cover the earth to around 70 degrees north and south. Originally a non-profit organization providing global distress communications for shipping (offering GMDSS services), Inmarsat is now a commercial organization with products aimed at land-based users as well as those at sea.

Inmarsat has developed a series of networks providing sets of services (most networks support multiple services). They are grouped into two main sets – existing/evolved services and advanced services.

Selected services include Broadband Global Area Network, FleetBroadband and Fleet One.

The Broadband Global Area Network (BGAN) is a set of IP-based shared-carrier services. These services offer a shared-channel IP packet-switched service of up to 492 kbit/s (uplink and downlink speeds may differ and depend on terminal model) and a streaming IP service from 32 kbit/s up to X-Stream data rate (services depend on terminal model). X-Stream delivers the fastest, on demand streaming data rates from a minimum of 384 kbit/s up to around 450 kbit/s (service depend on location of user and terminal model). Most terminals also offer circuit-switched Mobile ISDN services at 64 kbit/s and low bandwidth (4.8 kbit/s) voice services. BGAN service is available globally.

FleetBroadband (FB) is a maritime service based on BGAN technology [31], offering similar services and using the same infrastructure as BGAN. A range of FleetBroadband user terminals are available, designed for fitting on ships - it is one of the oldest marine satellite broadband options and certainly the most reliable. FleetBroadband comes in 3 different terminals: the 150, 250, and 500. Each terminal reflects the max download speed of the unit (the 150 goes up to 150 kbps, etc.). FleetBroadband works most places on the planet, provides smooth connectivity for downloads, and remains a popular choice.

Inmarsat Fleet One is the newest satellite broadband option from Inmarsat. It is basically a lean version of a FleetBroadband

150. It runs at a max speed of 100 kb/s and offers very inexpensive airtime options, however with a significant additional limitation, as Inmarsat has created a special coverage map for the Fleet One.

In August 2010, Inmarsat had announced building of a constellation of three Inmarsat-5 satellites, as a part of a worldwide wireless broadband network called Inmarsat Global Xpress. The final, third satellite was launched in 2015. The satellites operate at Ka-band in the range of 20–30 GHz. Each Inmarsat-5 carries a payload of 89 small Ka-band beams which combined will offer global Ka-band spot coverage. In addition each satellite carries six fully steerable beams that can be pointed at commercial or government traffic hotspots. According to Inmarsat, Global Xpress should deliver download speeds in excess of 60 Mb/s to a 60 cm dish [32].

III. BROADBAND MARITIME COMMUNICATION SOLUTIONS

For sea and ocean environments a number of research and implementation projects have been undertaken, seeking to employ inexpensive, broadband communication solutions, such as popular Wireless Local Area Network (WLAN) and Wireless Metropolitan Area Network (WMAN) technologies, in maritime environment. These initiatives aim to minimize limitations of these technologies and utilize them in such employment scenarios, where they are able to provide users with clearly defined, predictable and reliable service level. Systems such as WISEPORT (Wireless broadband-access for SEaPORT) network in Singapore are good examples of such initiatives.

These initiatives can offer a very interesting functionality and prove to be very useful, if they are indeed deployed in accordance with maritime user's needs. However, all these systems are still terrain the basic limitations of their underlying transmission technologies: they are limited in coverage (WISEPORT network - 15 km from coastline), throughput (digital VHF system - 21 kb/s to 133 kb/s) or cost (LEO/ GEO and VSAT systems – still expensive due to the need of antenna stabilization).

A. Standard, broadband communication technologies

For relatively small seas surrounded by lands, to which the Baltic Sea undoubtedly belongs (its maximum vessels-to-shore distances do not exceed 100 miles), it seems to be reasonable to employ in maritime communications some of the technologies which have been successfully implemented in an on-shore environment. Technologies such as 3G/4G, WiMAX or even popular WiFi, are able to offer broadband communication with the global Internet at much cheaper price, as compared to satellite solutions. Their drawback is limited reliability, relatively short range and dependence on the on-shore infrastructure.

Investigations carried out in this field show that the maximum distance at which a transmission in a ship-to-shore scenario is still possible with such technologies still maintaining data rates acceptable for the majority of mobile services does not exceed 20 miles. Moreover, it is strongly dependent on the variety of deployment specific factors, such as quality of employed equipment and its configuration at both client and network end of the link. Additionally, a number of characteristics of maritime environment, such as variable position of the antennas due to wave conditions or attenuation caused by humidity, rain, signal reflection from water, lightning, makes such communication relatively unreliable and unpredictable compared to previously described, dedicated maritime solutions.

Despite these limitations, an on-shore, broadband communication system, deployed in a manner taking into account the specifics of maritime environment, radically outperform previously discussed data exchange methods (including expensive satellite systems) by providing throughput measured in tens of Mb/s. Of course, their relatively range limits their utility to coastal areas and direct communication between vessels located very close to each other in maritime terms.

From the above analysis it follows that there is evident lack of maritime wireless broadband terrestrial systems that could successfully provide a global support for growing needs of e-navigation solutions. The current, globally supported maritime communication systems, which are mainly based on conventional High Frequency (HF), Very High Frequency (VHF), and Ultra High Frequency (UHF) radios for ship-to-ship communication and satellite systems for long range ship-to-ship/shore communication either provide insufficient bandwidth or tend to be very expensive in both deployment and maintenance.

B. Harbor and anchorage-area installations

Satellite-based solutions offer almost global coverage and the ability to conduct a data transfer on the open seas, however at relatively high cost and with limited strict limitations on resources available to user, due to limited capacities of satellite links. These limited capabilities of satellite links most often prove insufficient for modern e-navigation services, while crews and passengers approaching ports and travelling over closed seas like Baltic Sea or even the Mediterranean Sea are interested in much faster data transfers, even at the cost of partly lower reliability on all sea areas.

To meet these expectations port authorities are known to deploy on-shore WLAN and WMAN installations, often based on WiMAX (and also WiFi) technologies. The relevant WiMAX standards include IEEE 802.16d, 802.16e and 802.16j. The 802.16d targets at the fixed wireless access while the 802.16e counterpart is designed to support the mobile applications. New services delivered by port-wide wireless networks (offered e.g., in Singapore - WiMAX, Antwerp and Northport - WiFi) include social networking and entertainment and in particular: email, broadband video and voice calls, video-on-demand, web-surfing, distance learning, etc.

Moreover, such communication capabilities prove to be very useful for ship crews, as new solutions offer a long list of productive applications, including: e-navigation, seamless ship-to-shore communication, easy access to company intranet and employee information as well as online access to databases and information downloads (for ship repairs, maintenance, weather maps, etc.).

Majority of port installations use WiMAX due to its range and reliability advantages. WiMAX, unlike WiFi, allocates users a guaranteed allotment of transmission resources and offers better connection quality due to in-build Quality-of-Service mechanisms [15-16]. Such capabilities allow "mission-critical" services to run smoothly even in an environment, where the level of available transmission resources is strictly limited. These characteristics, combined with the fact that WiMAX can deliver data rates of up to approximately 70Mb/s over considerable distances make it an attractive proposition for on-shore installations.

Unfortunately, there are also some drawbacks of WiMAX technology, which have to be taken into account. Since WiMAX, unlike WiFi, is a WMAN system, its hardware tends to be more costly than a simple WiFi gear, which limits its utility in simple private networks. Additionally, a reliable deployment of a WiMAX system often requires a licensed frequency band to be used, which requires a spectrum license – there are also some WiMAX hardware implementations intended for unlicensed bands, but reliability of such deployments is significantly lower.

In 2011, International Council on Social Welfare (ICSW) commissioned preparation of a report in order to learn more about how port-wide WiFi and WiMAX installations are helping seafarers to maintain closer contact with home, which is one of the top of their welfare concerns. The research showed that the majority of ports have not deployed a port-wide WiFi or WiMAX access system. Many of those that have, restrict access to such systems for seafarers on grounds of cost and security concerns. As a result, seafarers still do not have adequate access to Internet connectivity in ports to stay in touch with family and friends. Detailed results of the research (funded by the ITF Seafarers' Trust) have been published by ICSW in a research report "Developments in New Technology & Implications for Seafarers' Welfare: Seafarers' access to WiFi and WiMAX in ports" [33], and show, that despite advances in communications technology, seafarers' access to Internet services is limited even in port areas.

The report looked at presence of both WiFi and WiMAX in maritime ports. In a survey that brought responses from 72 ports around the world, only just under a third (32%), had port-wide WiFi and 10% had port-wide WiMAX. Of those ports with port-wide wireless networks, 58% allowed seafarers access to them – 38% for free. Only 26% of ports without port-wide access had plans for deploying a similar system in the future. The main reasons that respondents gave for not having port-wide wireless technology were lack of demand, concerns about security, and the cost of installation and operation.

C. *WISEPORT - Wireless-broadband-access for SEaPORT*

One of interesting deployments of WMAN technology in a harbor area has been performed by Maritime and Port Authority of Singapore (MPA), Infocomm Development Authority (IDA) and QMax Communications Pte Ltd (QMax) in 2008. The system created by the WIreless-broadband-access for SEaPort (WISEPORT) project [34, 35] consists of the infrastructure allowing ships to obtain a wireless broadband connectivity while operating in the Port of Singapore, up to 15 km from Singapore's southern coastline. Initially four maritime hotspots had been set up at the sites where there were intensive maritime activities.

With WISEPORT, Singapore was the world's first mobile WiMAX ready seaport. WISEPORT aimed at enhancing the pro-enterprise environment for the maritime industry, improved operational and business efficiencies, enhancing human communications and opening doors to new business opportunities that were previously hindered by high satellite communication costs. Activities that had to be done on-shore, such as regulatory filings, electronic data exchanges and access to Internet-based applications, can now be replicated off-shore.

QMax, the appointed operator for the WISEPORT services, was offering free 512kbps unlimited data access plan during the first year of the WISEPORT launch. Subscribers to this special package received a thumb drive-sized WiMAX modem which could be used to access wireless broadband anywhere from the southern port waters and offshore islands to mainland Singapore.

D. *Multihop maritime communication systems*

Having witnessed the utility of broadband WLAN and WMAN communication technologies in maritime environment and confronted with their inherent range limitations, some research has been done in the past, which indicated that multihop transmission could be employed to mitigate the problem. In such networks a client station can be used to provide connectivity to other client stations, effectively extending the range of the system – with a sufficient number of participating vessels, vast areas can be covered without the need for operator-provided infrastructure. For the above functionality to be possible, a relatively complex set of self-organization and autoconfiguration mechanisms need to be deployed, to allow the network to cope with its dynamically changing structure, quality of communication over its particular radio links and network traffic conditions. A wireless multihop network capable of such autonomous operation is often called a wireless mesh network. Such a network still requires a point of traffic exchange allowing it to pass the traffic with external systems. An on-shore base station or an off-shore satellite link can be employed for this purpose.

Of course, the employed communication technology still has a fundamental impact on the system's operation, as its parameters directly determine a maximum range between neighboring vessels over which a communication can be performed and its QoS parameters.

1) *TRITON: High-Speed Maritime Wireless Mesh Network*

One of the initiatives taking the described approach is a TRI-media Telematic Oceanographic Network (TRITON) project [36], launched with the objective to develop a system for high-speed and low-cost maritime communications in narrow water channels and shipping lanes close to the shore.

The TRITON project has developed a ship-to-ship/shore mesh network that provides a high speed communication system that can operate reasonably well in busy shipping lanes, narrow water channels and traffic lanes close to shorelines. In TRITON, the coverage extension is achieved by forming a wireless multi-hop network amongst neighboring ships, marine beacons and buoys. The multi-hop wireless network organized on the sea is in turn connected to the terrestrial networks via land stations, which are placed at regular intervals along the shoreline. The TRITON network resembles a vehicular ad hoc network (VANET) based on cars but with some unique characteristics given by the distinct ship mobility pattern, position awareness of neighboring ships via the AIS, wave rocking movement and wave occlusion due to sea surface.

The envisaged system is a wireless mesh network based on the IEEE 802.16 standard. An example TRITON topology - architecture is depicted in Fig.3.

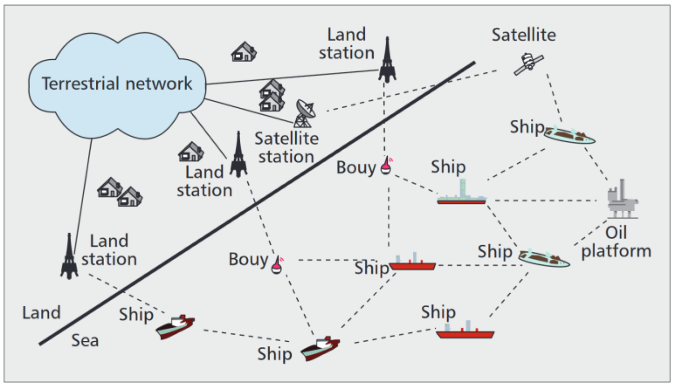

Fig. 3. TRITON system topology [37]

In order to successfully develop such a maritime mesh network, a number of challenges such as sea surface movement and strong sea wave reflections, had to be overcome. The TRITON team successfully implemented the mesh node with antenna switching for maritime communications that allows overcoming the above challenges.

In order to ensure a higher reliability of communications TRITON proposed the proactive routing protocol called MRPT (MAC-based Routing Protocol for TRITON) [37]. MPRT uses WiMAX mesh MAC control messages to propagate routing information from the land station to the ships. The proactive operation is achieved with limited control overhead compared to Optimized Link State Routing (OLSR), by enabling additional routing messages which are piggybacked on existing MAC control messages. This in turn makes multiple routes readily available in a tree structure. As such, a newly arrived node can join the network immediately, thus reducing the initial packet delay. In order to increases the network robustness alternative routes are available as backup for route switching when an existing link is broken.

In designing the mesh network, it was also important to consider scheduling protocols to be used in such a multi-hop network. The WiMAX mesh TDMA based MAC enables efficient bandwidth utilization through time slot allocation. Coordinated distributed scheduling specified in the WiMAX mesh standard was adopted for use in the test maritime system, as it is able to allocate time slots in a distributed manner directly among neighboring nodes without involving the land-based base station. This reduces the control overhead since scheduling information does not need to be delivered to stations across multiple transmission hops.

The developed mesh nodes use GPS to achieve time synchronization. As ships may travel between countries and in international waters, the frequency usage must follow regulations of various countries and related international bodies such as IMO and ITU. To allocate frequency band internationally for maritime mesh communications is hard task since most of bands are occupied. One of proposed solutions is to utilize white spaces based on cognitive radios. Besides the developed MAC based redundant routing protocol, network coding may be used to increase the network reliability and to minimize possible package loss due to link broken induced by sea wave.

For areas of low station (i.e., vessel) density (insufficient for the mesh network to form) it would still be necessary for the vessels to switch back to legacy satellite communication, with its high hardware and operational costs.

2) Maritime ITS with Intelligent Middlware for Mesh Networks with Satellite Communications

Another of solutions utilizing the abovementioned approach is a proposal being an outcome of an international collaboration between I2R (Institute for Infocomm Research, Agency for Science, Technology & Research, Singapore) and NICTA (National ICT Australia) [38]. The proposed system merges the high speed maritime mesh technology with legacy satellite communications by means of intelligent middleware, which also performs link specific protocol optimizations.

Similarly to TRITON and some other initiatives presented in literature IEEE 802.16 mesh and 802.16e standards were chosen as the technology for multi-hop inter-ship communications. To evaluate the feasibility of the system with WiMAX radios, the research team had conducted series of experiments. Investigations of large-scale path loss and performance of WiMAX in the 5.8 GHz band [15-16] confirmed the feasibility of deploying a WiMAX based maritime mesh network. The obtained performance results for the WiMAX MAC in multihop mode in a maritime communication scenario show that the network throughput, delivery ratio and the packet delay closely depend on the sea states, as well as the direction of the sea wave relative to the vector connecting nodes attempting to communicate.

Novel elements proposed in [39] included an optimized transport protocol for congested satellite links and an enhanced IP telephony system for those links. These have been integrated in the prototype satellite router device also consisting of the Inmarsat BGAN / FleetBroadband modem interface and command set, which was developed to aid the integration of satellite services.

The satellite router device has been used as a platform for an intelligent middleware development for an integrated mesh and satellite system. Figure 4 shows the system's architecture. The middleware acts as an access router for local on-board applications from user devices or ship's PCs which may have business or social applications. Other ships which also carry the standard equipment act as relay nodes in the mesh network and can forward the traffic towards a shoreline base station (BS).

When there are enough nodes available to provide ship to shore (or ship to ship) communications, end-to-end connectivity can be established in the maritime mesh network.

In cases when the end-to-end connectivity cannot be guaranteed, satellite communications may be used as an alternative way of communications for on-board users. While FleetBroadband [31] has been designated as a primary solution to be used in such a case, any other maritime satellite service can be used in its place.

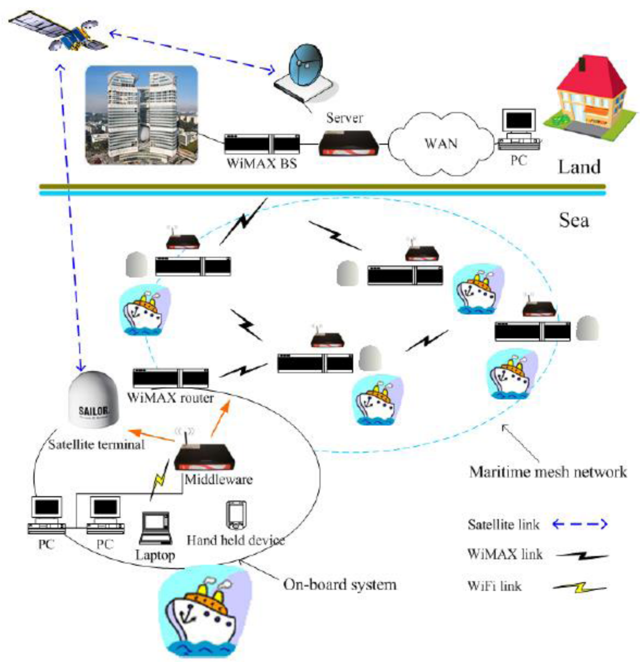

Fig. 4. System architecture for an integrated maritime mesh network with satellite system [38]

Apart from the most significant, maritime mesh network initiatives described above, there are also other examples of such systems to be found in literature – some of them attempting to maximize other parameters than attainable throughput.

One of such examples is a mesh network operating in 27MHz/40MHz with a single link ranged up to 70 km [40] which effectively guarantees the ubiquity of communication in enclosed maritime areas such as Baltic Sea. In this case however, the maximum attainable throughput is only about 1 kb/s, which is far from requirements of most modern services utilizing digital connectivity.

Concepts of other maritime mesh or ad hoc networks were also studied in [36-37, 41-45].

IV. NETBALTIC PROJECT – HETEROGENOUS WIRELESS COMMUNICATIONS OVER THE BALTIC SEA

The presented overview of communication technologies currently employed in maritime environment and results of abovementioned projects aimed to facilitate a digital maritime communication, clearly show the lack of broadband, reliable and affordable solution for this task. This conclusion is further reinforced by more detailed studies of reverent literature [10-19].

In this situation, researchers from Gdansk University of Technology, Poland, in cooperation with several Polish industrial partners including the National Institute of Telecommunications, the Institute of Oceanology of the Polish Academy of Sciences, and companies (DGT-LAB and NavSim), are currently working on deployment of heterogeneous maritime communication system, capable of transparently utilizing diverse range of communication technologies. Such capability will allow the system to use any and all communication capabilities of the maritime vessel in the process of dynamically creating a data transmission infrastructure. The system is designed to make extensive use of self-organization and autoconfiguration principles to maximize the area from where digital communication is possible.

The main aim of the netBaltic project is to develop and deploy a broadband wireless communication system providing connectivity in a heterogeneous wireless environment, able to meet the requirements of e-navigation services. In particular, the lack of reliable high-throughput communications is currently the major barrier in e-navigation implementations. Limitations of any single group of deployed communication technologies:

- HF and VHF technologies, although offering long link ranges are able to provide only a very limited bandwidth,
- higher frequency WLAN and WMAN technologies are severely range-limited,
- satellite communications technologies are often too expensive, especially for smaller vessels,

have shown, that while optimizing a chosen technology to operate in the maritime environment (as attempted in the TRITON project by implementing homogeneous WiMAX mesh networking solutions with modified MAC mechanisms and dedicated beamforming antennas) can bring beneficial results, it will not provide what can be called a general solution. In this situation, a heterogeneous system, automatically making use of the most efficient available technology could be seen as a possible answer to the requirements of modern e-navigation services.

In netBaltic system three different types of network organization principles are used (see Fig. 5), depending on communication opportunities available to a vessel in a particular location:

- in areas where direct connectivity with on-shore access networks is possible – a heterogeneous, multi-base station access network, supporting seamless handover and mobility management mechanisms (zone - area A),
- outside zone A, but in areas of sufficient vessel density to form a multi-hop communication network – a self-organizing mesh network, capable of transparently utilizing different communication technologies (zone B),

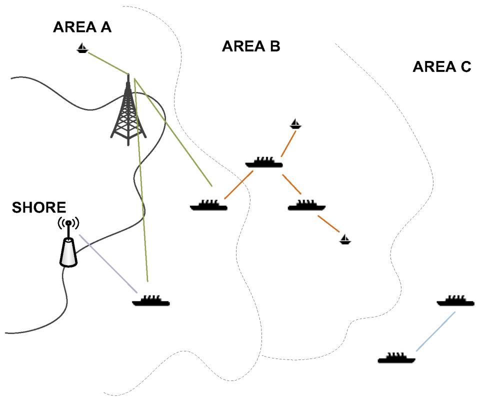

Fig. 5. Communication areas of netBaltic system

- outsize zones A and B, where real-time network connectivity with on-shore infrastructure is not possible even with multi-hop transmission – a Delay Tolerant Network (DTN), allowing sizable, protected data containers (tens of MBs) to be exchanged between vessels as opportunity arises, to be eventually delivered to zones A or B for final delivery to their destination.

This pioneering architecture is planned to be the major outcome of the netBaltic project realized in the years 2015-2018 and co-funded by the Polish National Centre for Research and Development [46-47].

The mechanisms employed in the first zone (zone A) include mobility management solutions to provide uninterrupted ship-to-shore connections across a set of different wireless technologies in a one hop communication environment. Multiple network access infrastructures, deployed by different operators and utilizing popular wireless technologies are expected to be encountered in this zone, like cellular solutions (3G/WCDMA/LTE) or broadband terrestrial systems (e.g., WiMAX, WiFi), as well as technologies specifically dedicated for maritime usage (e.g. RADWIN JET 5000). The netBaltic system employs network-layer mobility management mechanisms to provide uninterrupted IPv6 communication [48]. Additionally, different wireless technologies are integrated by the use of a layer 2.5 logical interface employing mechanisms for intelligent channel selection and seamless switching between transmission techniques.

The second area (area B) is supported by means of a heterogeneous, self-organizing mesh network, capable of providing connectivity in both ship-to-ship and ship-to-shore scenarios with a complete set of its essential mechanisms located in the network layer, and thus independent of specific transmission technologies employed. A hybrid routing protocol is utilized to simultaneously maintain multi-hop routes to multiple gateways to external networks (mainly on-shore base stations, but possibly also shared off-shore satellite uplinks) and allow a current route to be discovered to any reachable vessel in zone A or B [49]. Additionally, a number of mechanisms have been deployed to allow the dynamically changing mesh structure to efficiently operate in the maritime environment – they include, for example: reliable transmission procedures for inter-vessel links, transmission route recovery mechanisms, dynamic rerouting of traffic to alternative gateways or fast rerouting around failed network links and nodes. Additional information from AIS system will be used to provide increased efficiency and reliability of the proposed solution, by giving the system an ability to predict ongoing changes in the mesh network structure for purposes of providing a more reliable service and communication efficiency improvements.

It is evident, that despite the robustness of zone A and B mechanisms, real-time network connectivity will not be available in some sizable areas. To allow a number of non-real-time services to successfully function in these areas, a DTN network mechanisms have been developed.

The last area (area C) is dedicated for nodes located far away from the rest of vessels, and as a result, being able to establish connections only very occasionally. This group of mechanisms utilizes a concept of a dedicated, delay-tolerant network system – data to be delivered is packaged into compressed, cryptographically protected containers and exchanged between maritime vessels as they approach each other during their planned travels, until such container reaches an area where real-time connectivity allows the date to be delivered to its final destination. For the purposes of optimizing the delivery of containers, information from AIS system is utilized. The functionality provided in area C is sufficient for many e-navigation services, such as navigation or weather map distribution and can also prove useful for purposes of measurement data delivery from a diverse range of manned and autonomous measurement platforms (such as buoys).

Due to the presented, three-zone architecture and the ability to transparently utilize any IPv6-compatible communication technology, the netBaltic promises to provide maritime vessels with data exchange capabilities closest to ubiquitous then these offered by any single communication technology. Moreover, its heterogeneous nature allows new technologies (such as VDES) to be integrated effortlessly, making the system a self-evolving one.

V. Conclusions

This paper presents an overview of popular, digital transmission systems and technologies currently being employed in maritime communication, which can be used as elements of Maritime Intelligent Transportation Systems. Presented systems include both solutions based on well-known terrestrial wireless technologies and major satellite systems.

Marine oriented networks and systems presented in the paper are depicted in Figures 6 and 7 in two contexts. The first one, presented in Figure 6, takes into account their available bandwidth and the communication range they offer. The second one (Figure 7) places them in the context of both IMO mandated services and new diversified e-navigation applications accessible due to communication capabilities offered by broadband wireless technologies.

The overview provided in the paper as well as information shown in Figures 6-7, makes limitations of currently employed, dedicated maritime solutions evident (limited throughput and/or high cost). A few of the most important research initiatives dedicated to improving the situation, by facilitating deployment of specific, broadband communication solutions (mostly based on WLAN and WMAN technologies) in maritime environment have also been described.

As an alternative to these systems the netBaltic project with its innovative, heterogeneous, multi-area architecture has been presented. With the core elements of the netBaltic system scheduled to be developed in 2018, it seems that many organizations and Baltic research initiatives currently developing e-navigation services can expect to be provided with a robust communication platform. Details of its mechanisms and results of their testbed verification scenarios are presented in a number of paper published by the project's participants [41, 46-49].

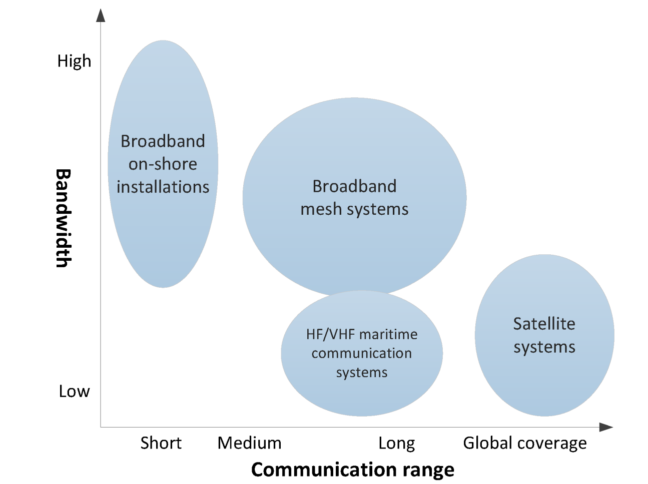

Fig. 6. Transmission bandwidth and communication range of maritime systems

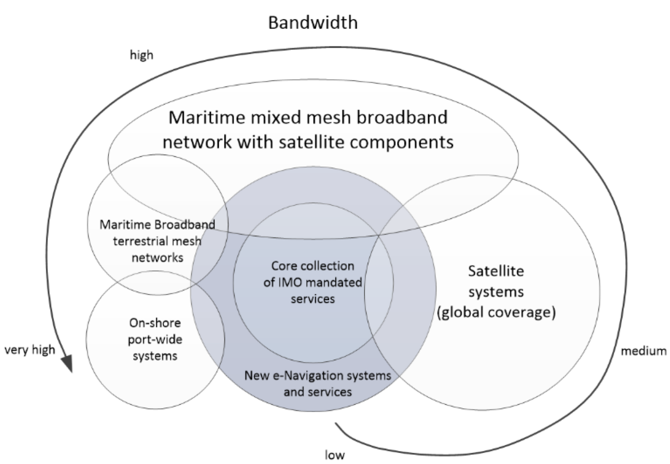

Fig. 7. Service centric taxonomy of broadband or semi-broadband maritime systems

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