Opportunities and Challenges of Maritime VHF Data Exchange Systems

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Abstract

Two subsequent World Radiocommunication Conferences, held in 2015 and 2019, have concluded the frequency allocation in VHF bands for the two-way maritime VHF Data Exchange System (VDES) via terrestrial and satellite radio frequency links respectively. The modernization and digital evolution of maritime communications was initiated in 1990's by adopting Automatic Identification Systems (AIS) for ship to shore, ship to ship and shore to ship communications for a variety of applications, targeting safety at sea. The frequency allocation for VDES has been a significant step forward towards achieving the same goal by facilitating solutions for enhanced navigation, broadcasting essential information and many other emerging applications.

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IJSC&N Special Issue "Opportunities and Challenges of Maritime VHF Data Exchange Systems": Guest editorial message

Two subsequent World Radiocommunication Conferences, held in 2015 and 2019, have concluded the frequency allocation in VHF bands for the two-way maritime VHF Data Exchange System (VDES) via terrestrial and satellite radio frequency links respectively. The modernization and digital evolution of maritime communications was initiated in 1990's by adopting Automatic Identification Systems (AIS) for ship to shore, ship to ship and shore to ship communications for a variety of applications, targeting safety at sea. The frequency allocation for VDES has been a significant step forward towards achieving the same goal by facilitating solutions for enhanced navigation, broadcasting essential information and many other emerging applications.

The allocation of frequencies at WRC-19 for VDES via satellite (VDE-SAT), reduced regulatory risks in the deployment of VDES for two-way communications, to and from vessels via satellite. At the same time, the allocated frequency plan has raised new technical challenges for the development of space segment technologies aiming at feasible and viable system solutions for end-to-end system deployment. This has made VDES an area of active research seeking academic as well as industrial solutions for end-to-end VDES terrestrial and satellite components sharing common system resources.

The development and deployment of AIS services in the 1990s were primarily intended to function as a tool for ship identification, collision avoidance and vessel traffic monitoring. However, the AIS success in terms of large-scale proliferation and feasibility quickly spawned a host of additional application, which in turn led to the birth of the Application Specific Messages (ASM) concept. The standardization of ASM allowed for even more innovative use of the AIS technology and increased traffic on the AIS channels. Thus, in the 2000s the traffic load on the AIS channels in dense shipping areas increased significantly. To avoid channel overload and possible loss of safety critical AIS messages, it was deemed logical to relocate non-safety related services away from the AIS channels. The simple solution for that was to move the ASM messages off the AIS channels. In the process of defining the spectrum requirements for ASM, additional maritime communication applications surfaced. As they could not all be accommodated by ASMs, the concept of VHF Data Exchange (VDE) was defined and the VHF Data Exchange System (VDES) was born.

In essence, the VDES provides a variety of means for the exchange of data between maritime stations, ship-to-ship, ship-to-shore, shore-to ship, ship-to-satellite and satellite-to-ship. The VDES is a multi-component system comprising of the automatic identification system (AIS), application specific messages (ASM) and VHF data exchange (VDE) in the VHF maritime mobile band (156.025-162.025 MHz). Although primarily a terrestrial system, VDES also allow for satellite use. In particular, the VDE has defined both a terrestrial component (VDE-TER) and a satellite component (VDE-SAT).

Frequencies for the terrestrial components of VDES, ASM and VDE-TER, was identified and included in the Radio Regulations (RR) at the WRC-15. Consideration of VDE-SAT was deferred to WRC-19 which allocated and identified to VDE-SAT the same frequency bands as for VDE-TER.

Resource usage and management differ between the various components of the VDES. The frequency and time-slot allocation within AIS are primarily based on a self-organizing protocol, where each AIS transponder announces when they will transmit based on a slot map created by listening to other AIS transponders transmission announcements. This allows for an efficient use of the frequency resources without a central resource management. ASM depend on a similar self-organizing protocol as AIS, but with a higher ratio of random access and fixed access allocation transmissions. This is due to the expectation that ASM transmissions from ships will be more one-off transmissions and that ASM transmissions from base stations of navigation and safety information to be repeated regularly will benefit from reserving resources. Thus, ASM is self-organizing like AIS, but with more use of central resource management.

For VDE, including both VDE-SAT and VDE-TER, the link access is controlled by central resource management. However, there are provisions for how ships can utilize the frequency resources when no VDE-TER shore station or VDE-SAT satellite are available to control the central resource management. In VDE resource management and assignment is handled by "bulletin boards" and "Announcement Signaling Channels". VDE-TER shore stations use the Terrestrial Bulletin Board (TBB) to configure the frequency usage within their control area and VDE-SAT satellites use the Satellite Bulletin Board (SBB). The TBB and the SBB serve the same purpose, but they contain slightly different information to account for the operational distinctions between VDE-SAT and VDE-TER. A VDE-SAT satellite provide a very large coverage area, so at any given time multiple VDE-TER shore stations may be within that coverage area. Given that VDE-TER provides for a higher data throughput, the system and spectrum efficiency of VDES are maximized when vessels take advantage of VDE-TER shore station coverage when that is available. To accommodate this, a VDE-SAT satellite should respect the resource assignments of VDE-TER shore stations.

Requirements and schemes for resource sharing between VDE-TER and VDE-SAT are closely linked to the frequency plan used for VDE. The frequency plan decided at WRC-19 stipulates VDE-SAT up- and down-link in both upper and lower legs of RR Appendix 18 with 50 kHz dedicated in each leg. The remaining 100 kHz in each leg of RR Appendix 18 are dedicated to VDE-TER. These 100 kHz can also be used by VDE-SAT if not used by VDE-TER, i.e. for vessels outside VDE-TER shore station coverage. With separate frequency resources dedicated to both VDE-SAT and VDE-TER, no elaborate sharing scheme between VDE-SAT and VDE-TER is needed and the two VDE components can independently maximize the system and spectrum efficiency. In addition the satellite component can utilize frequency resources not used by the terrestrial component.

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Figure 1: VDES Frequency Plan and Subsystem Definitions [1]

The aim of this special issue of IJSC&N has been to shed light on potential use cases and relevant technologies applicable to VDES. The first part of this special issue brings together six papers selected among manuscripts submitted to this call addressing verity of topics ranging from channel modelling, antenna technologies, random access protocol as well as geo-localization and ranging applications.

In the paper titled "Satellite forward VDES channel modeling and impact on higher-layer performance", G. Giambene et al. use the collected data from a measurement campaign to develop an ON-OFF model for the VDE-SAT downlink channel taking into account the multipath due to the surface reflections and wide-beam receiving antenna. The channel model is subsequently used to assess the effect of link layer coding schemes to combat packet loss during deep signal fading. The proposed technique is particularly important for VDE-SAT downlink broadcasting content such as ice charts to multiple users.

A review of the state-of-the art regarding on-board antenna technologies in VHF bands, particularly for small satellites and CubeSats in Low Earth Orbit (LEO), has been reported by V. Gomez-Guillamon Buendía et. al in their paper titled "Review of antenna technologies for very high frequency Data Exchange Systems". The paper provides a comparative study of antennas for VDES applications taking into account relevant performance metrics.

The third paper in this special issue entitled "Performance bounds for VDE-SAT R-Mode" by J. Safar et al., reports on the growing interest to utilize VDES satellite and terrestrial components to deliver positioning and timing services to vessels, as commonly referred to as ranging mode or R-Mode. The paper in particular investigates the feasibility of using satellite VDES transmission by establishing statistical performance bounds on the ranging error. Reported results complement previous findings of the same authors on the performance bounds obtained for terrestrial VDE waveforms.

The fourth paper entitled "VDES R-Mode performance analysis and experimental results" by M. Wirsing et al., applies signal processing techniques such as Kalman filtering for position and velocity tracking based on experimental data collected from VDES terrestrial trails. Using the experiment results, authors remark that terrestrial VDES R-Mode is capable of achieving a 95th-percentile horizontal position error of 22 m.

In the paper entitled, "VDES R-Mode: Vulnerability analysis and mitigation concepts" F. Lazaro et al., report on the use of VDES and its potential vulnerability as a contingency for maritime positioning and navigation systems in case of disruption of the Global Navigation Satellite Systems (GNSS). Authors propose an authentication method for VDES navigation messages.

Finally, in the sixth paper of this special issue R. Andreotti et al. in their paper titled "On-Field Test Campaign Performance of VDE-SAT Link ID 20 over Norsat-2 LEO Satellite", analyse experiment results of their test campaign based on VDE-SAT uplink random access channel transmissions. The paper also reports on the use of demodulation techniques to successfully decode overlapping messages, confirming the robustness of the VDES protocol against self-interference from random access channel transmissions.

In closing this editorial message, we would like to thank all authors of submitted manuscripts for their excellent contributions. We would also like to recognize the contribution of reviewers for their valuable comments and suggestions to enhance the quality of the papers.

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