VDES Performance Evaluation for Future e-navigation Services

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Keywords: VDES, AIS, Satellite, VHF, e-navigation, Simulation.

Abstract: E-navigation aims at increase safety and efficiency of navigation, defining reliable data exchange formats and communication channels between either ship to ship or ship to shore. New technological advancements start from the consolidation of Automatic Identification System (AIS), which is mandatory in some classes of ships for the notification of the position and to send distress signals. In pair with AIS baseline services, additional services are gaining momentum and are available in state of the art equipment, including the handling of sending and receiving Application-Specific Messages (ASMs). In this direction, the VHF Data Exchange System (VDES) standard was recently introduced, to improve on both messaging capabilities and system flexibility (standardizing the use of satellite channels) as well as to allow higher bitrates for application messages with regard to AIS and ASM. In this paper, we reviewed the main characteristics of VDES, then we carried out a technical analysis of the new communication standard in terms of channel compositions, supported rates, access schemes and latency. Finally, we focus on the performance of two possible future VDES applications, namely "dematerialization" and "towage" through a MATLAB model of the VDES communication channels.

1 INTRODUCTION

The International Maritime Organization (IMO) developed the e-navigation strategy to increase safety of navigation through a better organization of data on ships and on shore, better data exchange and communication between ships or ship to shore (and vice-versa). According to the official IMO definition, e-navigation is "*the harmonized collection, integration, exchange, presentation and analysis of marine information on board 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*". E-navigation has been for long time associated to Automatic identification system (AIS) (IMO, 2001) technology, using communication in VHF bands and offering a transmission range of up to 10–20 nautical miles, accordingly to the used equipment.

AIS is an important framework for safety of navigation and it is a carriage requirement defined by the International Convention for the Safety of Life at Sea (SOLAS) for big-sized vessels (e.g, 300 tons and upwards). Because of its effective and useful technology, the use of AIS is often extended to vessels not complied with the carriage requirement (i.e., AIS Class-B) and allows other applications such as Aids to Navigation (AtoN), Application Specific Messages (ASM), Search and Rescue Transmitter (SART), Man Over-Board unit (MOB) and Emergency Position-Indicating Radio Beacon (EPIRB-AIS). This extended use of AIS technology has caused significant increase in VHF Data Link (VDL) load, which has become an active concern in IMO and International Telecommunication Union (ITU).

Because of increasing general demand of radio spectrum for digital communication (mobile phones and data), ITU issued recommendation ITU-R M.1842 (ITU, 2009) to define characteristics of an enhanced VHF radio systems for maritime mobile services. In addition, ITU defined techniques for efficient and standardized maritime communications at higher data rates (up to 32-fold) providing the core element of the upcoming VHF data exchange system (VDES), which has been standardized in the 2015 with the recommendation ITU-R M.2092-0 (ITU, 2015).

VDES aims at first complementing/extending and in the next future (tentatively by year 2019-2022), replacing current AIS, by providing a vast gamut of data exchange channels and methods. Thereby, the AIS radio channels will be resilient to overload as AIS populations increase, and new services will be enabled by the progressive introduction of alternative VDES channels.

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Luglio, M., Roseti, C. and Zampognaro, F.
VDES Performance Evaluation for Future e-navigation Services.
DOI: 10.5220/0006850200670075
In *Proceedings of the 15th International Joint Conference on e-Business and Telecommunications (ICETE 2018) - Volume 1: DCNET, ICE-B, OPTICS, SIGMAP and WINSYS*, pages 67-75
ISBN: 978-989-758-319-3

VDES supports terrestrial data communication as well as a satellite component, leveraging VHF radio channels. The traditional SAT-AIS (ESA, 2018) was provided as an added option to exploit the advantage of global satellite coverages for AIS broadcasting beyond the coastal areas, without increasing the actual terminal capabilities. On the contrary, the combined use of terrestrial and satellite channels is defined in the early stages of the VDES standards, as a design requirement. This represents an opportunity to offer worldwide coverage and facilitate the implementation of interoperable e-navigation and modernization of the Global Maritime Distress Safety System (GMDSS) by specific optimizations coming from the use of satellite communications.

The evaluation of VDES theoretical performance as inferred by a critical analysis of the standards is the first focus of the paper. Next, taking as a reference two VDES-compliant applications defined in the frame of an ongoing European Space Agency (ESA) project, named MARVELOWS (ESA, 2017), a preliminary feasibility study through a simulation campaign is presented and discussed.

2 VDES OVERVIEW

The VDES aims to provide an effective and efficient use of radio spectrum, enhancing the capabilities of AIS and addressing the increasing requirements for data exchange. New VDES channels and techniques enable higher data rates than those used for AIS. Furthermore, VDES network protocol is optimized for data communication so that each VDES message can be transmitted with a high confidence of reception, on either terrestrial or satellite VHF channels.

The VDES system supports the unique identification and location of all active maritime stations as a default service. For the purpose of identification, the Maritime Mobile Service Identity (MMSI) is used, as defined in the latest version of Recommendation ITU-R M.585 (ITU, 2012). Therefore, VDES comprises the functions of the existing AIS, the additional communication links for the exchange of Application Specific Messages (ASM) and further dedicated communication links enabling dedicated higher capacity VHF data exchange (VDE). Figure 1 depicts possible VDES communication options and includes in particular:

- Shore-to-ship (and vice versa) VHF terrestrial communications for AIS, VDE and ASM services;
- Ship-to-ship (and vice versa) VHF terrestrial communications for AIS, VDE and ASM services;
- Shore-to-ship (and vice versa) VHF satellite aided AIS services;
- Satellite broadcasting services for e.g., VDE messages of general interest.

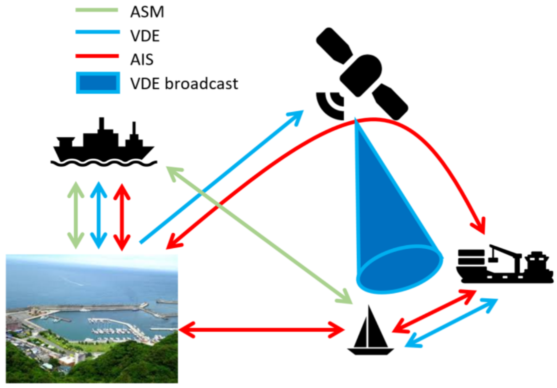

Figure 1: VDES/AIS communication framework.

VDES is currently a work-in-progress activity, where in the period 2019–2020 VDES is expected to replace AIS and evolved ASM services, to be part in year 2021 of a generalized maritime access, including Satellite channels. Therefore, today is the right time to define and study advanced services over VDES, exploiting the additional capabilities introduced by the terrestrial component (first to be introduced according the the VDES implementation roadmap), and by the satellite component later on.

3 USE OF VDES FOR FUTURE E-NAVIGATION SERVICES

The availability of a standardized messaging system extending current AIS capability will allow in the near future to define a wide set of standardized enhanced e-navigation services, tailored to specif user requirements and use cases.

Currently, several use cases associated to specific services are being defined. For instance we have the UKCM (Under Keel Clearance Management), defined by the Australian Maritime Safety Authority, Route Exchange Ship to Ship, Logistic services, etc (The Nautical Institute, 2015).

In this direction, the European Space Agency (ESA) project named "*Maritime Applications exploiting Reliable VHF data Exchange LOW cost System*" (MARVELOWS) (ESA, 2017), provided a feasibility study of VDES-related services starting from a complete understanding of the users and stakeholders needs. In particular, MARVELOWS project foresees the development of two upcoming VDES services:

– **Dematerialization**, which is aimed to share information among vessels navigating the same geographical area, typically delivered on paper on a weekly or even monthly frequency, in addition to nautical charts exchange and weather forecast updates.
– **Towage**, which provides a technological support for real-time communications between personnel on the field and headquarter during towage operations. The main information that could be exchanged are: start and end of the service, routes and anchorages, crew list, weather now-casting.

The definition of the corresponding use-cases (UCs) and operational scenarios has been then based following the IALA Guideline 1117 "*VHF Data Exchange System (VDES) Overview*" resulting in the identification of the following combination of IALA UCs, which for MARVELOWS Dematerialisation service are:

– UC5 Chart updates and publications;
– UC6 - Route exchange.

and for MARVELOWS Towage service are:

– UC7 Logistic and services.

In all these UCs, it is requested to perform one or a combination of ship-to-shore, shore-to-ship and ship-to-ship data exchange, with different communication requirements, which will affect the configuration of the VDES system. Such communication requirements are:

– *Message size* - either short or longer messages are possible; message size affects the selection of a specific VDES channel configuration and access scheme;
– *Message timing* - this indicates how frequent send a message and which scheduling scheme to adopt: periodic or sporadic/event-drive. This parameter affects as well the selection of a specific access scheme;
– *Message reliability* - Reliability refers to the guarantee of a message reception. Within some access schemes, collisions are possible with subsequent transmission failure. It is possible either to avoid collision (through suitable access scheme) or implement a retransmission function at the application layer;
– *Real-Time delivery* - A time interval may occur between the data availability and its actual transmission. It is possible to properly tune this time by properly select the access scheme.

More specifically, and in relation to message timing, the following classification can be taken as a general reference from the standards:

– *Static information*. Every 6 minutes or when data is amended (on request);
– *Dynamic information*. Dependent on speed and course alteration can vary from 2 s (i.e. speed $>$ 23 knots and changing course) to 3 min (i.e. at anchor or speed $<$ 2 knots);
– *Voyage related information*. Every 6 minutes or when data is amended (on request);
– *Safety related messages*. As required.

4 ANALYSIS OF VDES

VDES defines VDE terrestrial (VDE-TER) channels, enabling a seamless two-way data exchange between ships and between ships and shore in coastal coverage areas, beyond the capabilities of ASM. The communication range of VDE-TER is typically 20 – 50 nautical miles (NM) and the supported capacity is up to 32 times higher than AIS. VDE allows data exchange not bounded to the message structure of ASM, enabling a whole range of new applications which may require data exchange of higher volume and with different formats. In VDE-TER, data transmission is made in the VHF maritime mobile band, within the spectrum allocated for the uplink (ship-to-shore), namely VDE1-A, and for the downlink (shore-to-ship and ship-to-ship), namely VDE1-B. The spectrum can be used as 25 kHz, 50 kHz or 100 kHz channels and transmission leverage Time Division Multiple Access (TDMA) techniques in a synchronized manner.

In addition to VDE-TER, the VHF Data Exchange by satellite (VDE-SAT) is defined, to provide data exchange between ships and shore via satellite. VDE-SAT complements the VDE-TER outside the coast station coverage area, enabling a global coverage for VDES. Low Earth Orbit (LEO) satellites, with 600 km altitude, are considered at the present for typical VDE satellite solutions, altought other orbital configurations (i.e., GEO) are also possible according to the overall system design consideration. The technical characteristics of communications *ship-to-satellite-to-shore* and *shore-to-satellite-to-ship* are still under development and they will be reviewed at World Radiocommunication Conference WRC-19.

4.1 VDES Channels Configuration

The spectrum allocation for the whole set of VDES services is reported in figure 2.

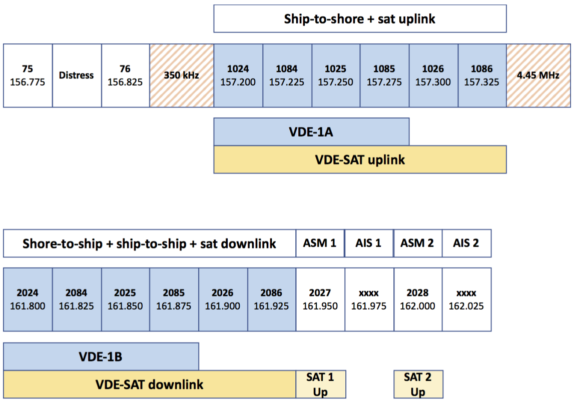

Figure 2: VDES transmission channels.

All the VDES components (legacy AIS, ASM, VDE-SAT and VDE-TER) leverage a common frame structure, which has a duration of 60 seconds and consisting of 2250 slots. A *time slot* is a time interval of approximately 26.667 ms. An *Hexslot* is a group of 6 consecutive time slots (duration = 160 ms). An *Uberslot* is a group of five *Hexslot* (duration = 800 ms). A *subframe* is a group of 15 *Uberslot* (duration = 12 s). Then, a *frame* is composed of 5 *subframe*. The basic frequency allocation plan respects the following rules to guarantee interoperability:

– 4 channels (1024, 1084, 1025 and 1085) shared for ship-to-shore and ship-to-satellite services;
– 2 channels (1026 and 1086) exclusively reserved for ship-to-satellite communications;
– 4 channels (2024, 2084, 2025 and 2085) shared between shore-to-ship, ship-to-ship and satellite-to-ship services;
– 2 channels (2026 and 2086) are exclusively reserved for satellite-to-ship communications.

It is important to highlight that the range of frequencies for VDE-TER and VDE-SAT is overlapping, so that specific mechanisms for VDES terminal to use either terrestrial or satellite slots must be defined. The coordination between the VDE terrestrial (ship-to-shore) and VDE-SAT uplink is achieved using *Terrestrial bulletin board* (TBB) and *Announcement signalling channels* (ASC).

4.2 VDES Burst Formats

The VDE-TER allows to alternatively use 25 kHz, 50 kHz or 100 kHz channels. The burst format varies depending on the channel bandwidth as shown in Figure 3.

The data field carried on each burst consists of multiple variable-length datagrams composed in turn

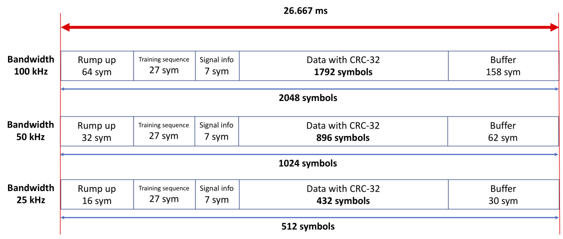

Figure 3: Burst format.

of the following fields: Datagram Type, Datagram Size, Destination (optional), Transaction ID (Optional), Datagram Sequence Number (for multi-segment datagrams), Source ID, Datagram Payload (variable size), Data padding and a 4-bytes CRC.

In each of above channels, three different Modulation and Coding Schemes (MCS) are applicable:

– *MCS-1*. Modulation = QPSK, Coding Rate = 1/2, communication distance = 50 NM.
– *MCS-3*. Modulation = 8-PSK, Coding Rate = 3/4, communication distance = 35 NM.
– *MCS-5*. Modulation = 16-QAM, Coding Rate = 3/4, communication distance = 50 NM.

VDE-SAT uses 50 kHz channels only. VDE-SAT downlink supports three different Physical Layer frame (PL-Frame) formats spread over 90 VDE slots, as summarized in the Table 1.

Table 1: VDE-SAT downlink formats.

Format	Usage	Modulation	Coding Rate	Duration
PL-Frame 1	Bulletin Board	BPSK	1/2	90 slots
PL-Frame 2	Multicast, ACK Announcements	QPSK	1/4	90 slots
PL-Frame 3	File segment transfer	8PSK	1/2	90 slots

VDE-SAT downlink can efficiently support multicast of multi-packet data formats and shore originated unicast data transfer via satellite. VDE-SAT uplink provides the following types of functionalities:

– *Two-way communications*; this includes:
  • Shore initiated information polling from ships;
  • Ship initiated inquiry for information from shore;
  • Ship initiated data transfer to shore
– *Transmit Only*. Collection of information from transmit-only VDES terminals. This can be either event-driven or periodic. The time slot and frequency band for this service should be assigned by the bulletin board and announcement signalling channels.

Table 2 reports the characteristics of the five PL-Frame formats defined for the satellite uplink.

Table 2: VDE-SAT uplink formats.

Format	Usage	Modulation	Coding Rate	Duration
PL-Frame 1	ACK and short messages	QPSK	1/3	5 slots
PL-Frame 2	ACK and short messages	CMP/QPSK	1/3	5 slots
PL-Frame 3	ACK and short messages	OQPSK	3/4	1 slot
PL-Frame 4	ACK and short messages	16APSK	3/4	1 slot
PL-Frame 5	Long packet file transfer	16APSK	3/4	30 slots

4.3 VDES Shared Medium Access

Access schemes used in the VHF maritime communications are defined in (ITU, 2014). Different TDMA-based techniques are available in VDES to access VHF channels in accordance to both the information type and update timing requirements.

VDES defines three modes of operations. The first is named "*autonomous and continuous*" where VDES stations must determine their own schedule for transmission, resolve scheduling conflicts with other stations. The second mode is the "*assignement*" one, allowing transmission by the reception of an explicit allocation message. Last, the "*polled*" mode is based on sending an response replying to an interrogation message. Operations in the polled mode do not conflict with operation in the other two modes, because the response is expected on the channel where the interrogation message was received. In order to support the above operation modes, VDES comprises five different access schemes.

4.3.1 SOTDMA

The *Self-Organized Time-Division Multiple Access* (SOTDMA) is the basic access scheme for AIS and can be used for VDE messages. Suitable for periodic transmissions (i.e. AIS-like), it allows to embed in the transmitted data also the indication of the Station ID and slot selected for the subsequent frames. This makes possible for receiving stations to build up a "map" of which slots are in use in the current and in subsequent slots, supporting autonomous and continuous operations.

4.3.2 RATDMA

The *Random Access Time-Division Multiple Access* (RATDMA) is suitable for sporadic (i.e. event-driven) short messages. RATDMA is used when a station needs to allocate a slot, which has not been pre-announced. This is generally done for the first transmission slot during data link network entry, or for messages of a non-repeatable type. A VDES station randomly selects a slot among the unused ones, and it assumes that such message can collide with other transmissions.

4.3.3 ITDMA

The *Incremental Access Time-Division Multiple Access* (ITDMA) is not used as a stand-alone access scheme but in combination with others (usually with SOTDMA). It is useful when there is a temporary change in the reporting period or to announce a not periodic message. In other words, ITDMA allows a station to pre-announce transmission slots for a non-repeatable message (autonomous and continuous operation). A station can begin its ITDMA transmission by either substituting a SOTDMA allocated slot or, by allocating a new, unannounced slot, using RATDMA. Either ways, this becomes the first ITDMA slot.

4.3.4 FATDMA

The *Fixed Assignment Time-Division Multiple Access* (FATDMA) is applicable for base stations on shore, for instance to support AtoN services. FATDMA allocated slots are used for repetitive messages delivery, assuming a pre-allocation of channels configured at the installation of the VDES terminals; FATDMA stations broadcast a Data Link Management message to advice other stations about FATDMA allocation.

4.3.5 CSTDMA

The *Carrier Sensing Time-Division Multiple Access* (CSTDMA) is suitable for low-cost transceivers, fully interoperable with SOTDMA (priority is given to SOTDMA). Only a slot per frame can be allocated with this scheme. Using this access method requires no strict synchronization (which in fact is granted by GPS units for the previous access mechanisms associated to Class A devices) but rather on timing derived by ongoing transmissions by other stations. This reduces the complexity of the station, while requiring to implement a "Listen before transmit" mechanism, limiting the number of bytes that can be transmitted in a slot.

5 PRELIMINARY ASSESSMENT OF VDES PERFORMANCE

On the basis of all configurations and methods presented in section 4, it is possible to perform a preliminary performance assessment of VDES based communication. Three application-oriented Key Performance Indicators (KPIs) were evaluated: *nominal bit rate*, i.e., the physical throughput that can be achieved (including overhead); *user bit rate*, which is the throughput as experienced by the application; *Data per frame*, which indicates the actual number of bytes that an application can send over a single frame.

These KPIs are necessary both to properly design the application and to identify the most suitable burst format and transmission channels for the target applications. In addition to that, the access mechanism shall be considered as well, in accordance to the application requirements in terms of reliability, and periodicity. Possible combinations are proposed in the following analysis as well.

Table 3 proposes the KPI values when considering VDE-TER downlink channels (VDE-1B) for shore-to-ship communications. Either SOTDMA or FATDMA can be used as access schemes and they present identical values. In fact, shore station can be assumed as a source of periodic updates (multicast or unicast) towards the vessels.

Table 3: VDE-1B SOTDMA/FATDMA performance.

Burst format	Channel bandwidth	Nominal bit rate (kbit/s)	User bit rate (kbit/s)	Date per frame (Bytes)
MCS-1	25 kHz	38.4	16.2	54
	50 kHz	76.8	33.6	112
	100 kHz	153.6	67.2	224
MCS-3	25 kHz	57.6	36.5	121
	50 kHz	115.2	75.6	252
	100 kHz	230.4	151.2	504
MCS-5	25 kHz	76.8	48.6	162
	50 kHz	153.6	100.8	336
	100 kHz	307.2	201.6	672

In the VDE-TER uplink, a high variability in both size and time of sent messages can be assumed. In case of large file transfer, ITDMA allows a better efficiency because the use of up to 5 slots per frame. On the other hand, ITDMA needs to pre-announce first the request of slots. Consequently, actual data transmission is affected by an "access delay" higher than 60 s (frame duration). Corresponding values are reported in Table 4.

Table 4: VDE-1A ITDMA performance.

Burst format	Channel bandwidth	Nominal bit rate (kbit/s)	User bit rate (kbit/s)	Date per frame (Bytes)
MCS-1	25 kHz	38.4	16.2	270
	50 kHz	76.8	33.6	560
	100 kHz	153.6	67.2	1120
MCS-3	25 kHz	57.6	36.5	605
	50 kHz	115.2	75.6	1260
	100 kHz	230.4	151.2	2520
MCS-5	25 kHz	76.8	48.6	810
	50 kHz	153.6	100.8	1680
	100 kHz	307.2	201.6	3135

In case the application data exceeds the allowed data per frame, the overall application-level transmission is performed over consecutive frames, then adding 60 s time contribution per extra frame in the message delivery time. To opposite, small sporadic messages (i.e. requests messages, reception acknowledgement, etc.) can leverage RATDMA. This latter reduces the access delay, while presenting a collision probability. In this case the KPIs are identical to those presented for SOTDMA/FATDMA (Table 3). As an alternative to RATDMA for small sporadic messages also CSTDMA can be taken into consideration, for low-cost receivers.

As far as the VDE-SAT downlink is concerned, the KPIs are reported in Table 5. Similarly to the terrestrial component, SOTDMA and FATDMA are the eligible access schemes.

Table 5: VDE-SAT downlink SOTDMA/FATDMA performance.

Burst format	Channel bandwidth	Nominal bit rate (kbit/s)	User bit rate (kbit/s)	Date per frame (Bytes)
PL-Frame 1	50 kHz	3.7	2.1	560
PL-Frame 2	50 kHz	34.1	9.6	2560
PL-Frame 3	50 kHz	51.2	28.8	7681

In the satellite uplink, the number of accessible slots per frame is constrained by the PL-frame definition. Therefore, without loss of generality we can refer to an ITDMA scheme as a representative of all the other schemes. Table 6 reports the corresponding performance. It is evident that the number of bytes hosted in a single frame is much lower than in the downlink.

Table 6: VDE-SAT ITDMA/RATDMA performance.

Burst format	Channel bandwidth	Nominal bit rate (kbit/s)	User bit rate (kbit/s)	Date per frame (Bytes)
PL-Frame 1	50 kHz	38.4	1.6	27
PL-Frame 2	50 kHz	76.8	1.6	27
PL-Frame 3	50 kHz	67.2	50.4	168
PL-Frame 4	50 kHz	134.4	100.8	336
PL-Frame 5	50 kHz	134.4	100.8	336

6 SIMULATION

Ad-hoc simulations are executed using the Matlab software with the aim to characterize the models of MARVELOWS applications over VDES. In particular, VDES channel structures have been implemented giving the flexibility in selecting the channel bandwidth (i.e. 25 kHz, 50 kHz and 100 kHz), the burst format and the access scheme. Only VDE-TER channels have been considered. In the simulation models, the traffic generation model allows the specification of the message size (or of a probability distribution of message sizes) and the message transmission scheduling. Mobility models was not implemented (i.e., ships entering and exiting the coverage area), because for the proposed initial assessment the total number of active ships in a given instant is sufficient.

We set up two different simulation scenarios: i) transmission of short periodic messages, representative of applications falling in the proposed *Towage* service, where periodic notification are expected; ii) the transmission of larger objects associated to future data-intensive applications, such as those related to the *Dematerialisation*. For the first category of service, it is considered of paramount importance to evaluate the overall load of the system and the maximum number of users able to successfully transmit short messages without losses. Here, the assumption is that messages fill a single slot and then data delivery is entirely performed within the current frame if no congestion occurs. For the second category of service, instead, data transmission can require multiple slots and then can span over consecutive frames depending on the message size, the maximum number of slots eligible per frame and the number of simultaneous transmissions. In this second case, an autonomous and continuous operational mode with different sized messages sent in parallel by multiple VDES terminals is assumed.

6.1 Simulation Results

The first test envisages a terrestrial 25 kHz channel for SOTDMA ship-to-shore communications. The frequency of these messages are assumed in the range of 1 – 6 min, while the number of active ships is increased from 500 to 9000 during the simulation.

Simulation output records the average number of slots occupied by the transmissions over the 2250 available. The results are shown in figure 4: with growing number of active ships, the average number of busy slots increases with a linear trend, unless the limit of slots is reached (i.e., at 2250 slots) when about 6000 ships are active. Nonetheless, when approaching (and exceeding) this saturation limit, the number of eligible slots for transmission is reduced, so that the competition lead to an additional access delay and messages loss, due to collisions of the initial RATDMA access. It is important to highlight that such service can co-exist with AIS legacy transmissions, alleviating the AIS channels by delivering additional information on the new VDE channels. Furthermore, VDES data channels can leverage satellite transmissions, to completely overcome VHF terrestrial ranges limits of 10–20 NM. In this way, VDES opens the way to a completely new classes of applications and overcome limitations of present AIS based services.

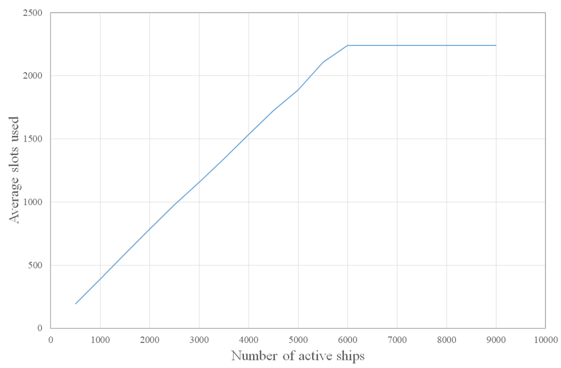

Figure 4: Simulation of AIS messages channel occupation.

Concerning the second test, a VDE-TER channel is used to allow transmission of large data messages, i.e. associated to images, navigation-related publications or chart updates related to the Dematerialization service. The goal of the test is to identify the system limit in sending relatively large-amounts of data, when the number of active ships increases. The following setup is considered:

- 250, 500, 750 or 1000 active terminals;
- message size is 250 Kbytes, which represents for instance the size of a good quality compressed image;
- each active ship transmits the message each 1 to 2 hours as sporadic guaranteed messages using terrestrial 100 KHz channel and MCS5;
- simulation duration of 2 days;

The first result presented is the evolution of slots occupation over time, shown in figure 5 for the different amount of active ships. Due to the necessity of delivering data without contention, a SOTDMA access scheme was enabled during these tests. The average number of slots occupied for transmission is 577, 1157, 1732 and 2179 when the number of active terminals goes from 250 to 1000 in steps of 250. The system shows a moderate load for up to 750 terminals, with a practical saturation of slots measured when the terminals are 1000.

When there is a large availability of slots (which in practice is experienced up to 750 terminals), the mes-

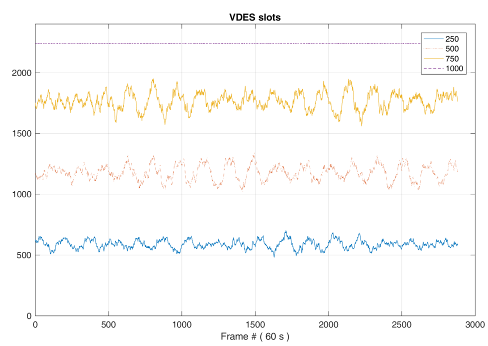

Figure 5: Slots used for VDE transmission as function of time.

sage transmission time is predictable and solely due to the access to the channel and the channel bitrate. In this situation, the messages delivery time is 80 minutes in average. On the contrary, when the number of active terminals is 1000, the effect of the access mechanism (SOTDMA)results into an average delivery time of 90.42 minutes. In this case, the experienced delay in average is similar to the average transmission intervals defined for the test (i.e., 90 minutes). In fact, if looking at figure 6, where the probability distribution function of the message full reception is reported (for all messages generated during the simulation), it is possible to verify that few objects are for sure delivered exceeding the 120 minutes. This means that, according to the application transmission period (which was defined within 1 hour to 2 hours), some data objects can be ready for the transmission while the transmission of the previous one is not yet completed: this can create problems to the application itself.

The modeling of the MARVELOWS applications, allowed to identify the target performance as function of the number of active terminals (expected into a given coverage area) and the channels in use. These aspects shall be carefully considered for the definition of future e-navigations systems. For instance, the expected maximum and average time for the delivery of a data object must be taken into account in designing the application, so that transmission periods and data sizes are carefully tailored to avoid communication overlaps.

As support for future applications definition, the combined use of satellite channels for VDES will provide a significant help, since some service can be migrated on satellite frequencies which offer wider coverage (e.g., not limited to the VHF terrestrial coverage of 10–20 NM) and may be less congested by

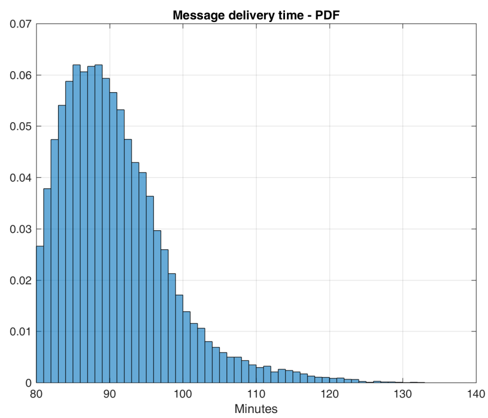

Figure 6: Probability Density Function of messages delivery times in saturation conditions (message load exceeding 100%, 1000 terminals).

the lack of legacy communications. This aspect will be addressed in future work, improving the simulation models and scenarios considered.

7 CONCLUSIONS

This paper proposes a detailed characterization of the upcoming VDES technology with the aim to provide a preliminary assessment of supported performance. VDES significantly improves on traditional AIS, by introducing additional channels and transmission mechanisms. Therefore, higher data rates and more resources foster the definition of new maritime data exchange applications. We proposed two possible advanced services leveraging VDES: Towage and Dematerialisation. The former represents a sort of enhancement of traditional AIS dealing with short messages, while the latter aims to extend data exchanges to larger messages. In this regard, VDES offers a good flexibility in configuring the service allowing different channel bandwidths, burst formats and access schemes. Nevertheless, the definition of new maritime services requires a fine-tuning and tailoring to the VDES link layer characteristics. In fact, application requirements need to meet timing and format constraints imposed by the standards. Simulation results provide a clear indication on such limits in terms of maximum number of served terminals and message delivery times. Awareness on such performance framework is deemed of paramount importance in the definition of future services, when the satellite component will become available and will increase the overall system capacity and service coverage out of the coastal areas.

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