**IALA eNAV WG 3 V-07.03.2016**

**Working Document towards a Preliminary Draft New ITU Report on VDE-SAT**

1. **Introduction**
2. **VDE-SAT, the essential supplement to coastal VDES [CLS]**
   1. **To fill the geographical and operational gaps of the VDES coastal network**

When analysing the ship density at global scale it clearly appears that coastal areas play a key role. It is then of common understanding and evidence that the VDES via the coastal network is the appropriate solution for maritime data exchanges between shore to ships and vice-versa. However, in parallel, it is very instructive to consider in detail the present status of the AIS terrestrial network. Marine traffic (can we quote that source?) is known as the most extended collaborative network with more than 2000 stations spread all over the World. Some areas like Europe, the US and Japan is largely covered, but others like the West of Africa or the South West of Asia are much less covered. Figure 1 illustrates this well.



Figure 1: AIS costal stations location (green point) and AIS data coverage (red points) (derived from MarineTraffic). *CLS to check with Marinetraffic that we are authorized to publish this CLS outputs.*

It is difficult to imagine that countries, such as Indonesia, composed of thousands of islands, could be equipped as largely as Europe is today. One of the difficulties is to find an appropriate hosting site, especially with a reliable power supply. Figure 2 that represents the 10 minutes distribution of terrestrial AIS data over 3 consecutive days in the Gulf of Guinea illustrates some critical gaps on routine operations.



Figure 2: Representation of the 10 minutes distribution of terrestrial AIS data over 3 consecutive days in the Gulf of Guinea.

Figure 3 exemplifies the high variability observed on the distribution of AIS messages collected from coastal stations. Such high variability indicates severe disruption to ship tracking and, in the future, potential disruption to VDES terrestrial communications. These problems of infrastructure distribution, reliability, maintenance in remote, difficult to access areas, or with insufficient budget or technical support issues are difficult to solve and affects many maritime zones.



Figure 3: High variability observed on the distribution of AIS messages collected from coastal stations (Gulf of Guinea, grey line corresponds to sunrise with possible activation of power generators on some sites)

In this context, the VDE-SAT appears as an opportunity to fill the previously mentioned gaps of the terrestrial VDE for coastal areas that are not in the range the current AIS coastal stations network offers, or to provide redundancy in the operations. One can also imagine that the VDE-SAT downlink services could be routinely optimized in order to complete the present terrestrial coverage.

* 1. **To expand of the VDES from coastal area to global coverage**

The VDE-SAT, based on a constellation of LEO satellites, is naturally the adequate tool to extend the terrestrial VDE capabilities to long-range communications. The implementation of the SAT-AIS has already demonstrated such evidence as Figure 3 illustrates. The intercontinental maritime lines are precisely drawn. The navigation in the Northern Arctic latitudes is also shown where the terrestrial network is lacking.



Figure 4: Comparison of one day of terrestrial AIS data (green dots) to one day of satellite AIS data (blue dots) - April 2015.

* 1. **Use case descriptions**
     1. **Distribution of maritime safety information**

The MSI (Maritime Safety Information) consists in navigational and meteorological warnings, meteorological forecasts, and other urgent safety-related messages broadcast to ships. The distribution of MSI is realized using the VDE-SAT downlink to broadcast information from the LEO satellite to the vessels. The messages content shall mainly refer to what is applicable to the maritime areas included in the satellite footprint along its track. A priority is associated to each of the messages in order to allow the Captain, and members of the watch, to prioritize the type of information to be displayed according to their needs. Moreover, the on-board Electronic Chart Display and Information System (ECDIS) acts as an automatic filter in a way that the seafarer only visualizes the MSIs that are on its route plan. Useful safety information may concern the following topics:

* Warnings of severe live or forecasted weather conditions to make the trip as safe and comfortable (passengers trip) as possible,
* Warnings of navigation hazards like dangers at sea (floating objects like containers, offshore structures, drifting buoys or ships...) (Figure 4),
* Route information, protected marine environment areas, restricted navigation zones...,
* Piracy or armed robbery at sea information including scene identification, warnings, procedures for example with the schedule plans for convoys with security resources (to be discussed)...



Figure 5: Example of danger at sea caused by a ship capsize in the Pacific ocean.

Some areas of navigation require specific dedicated information. It may be ice charts and bulletins in the polar region. It may also be tides, sea level, or current data forecast for port entrance or strait passages. The mariner can then take benefit of Under Keel Clearance ‘gate’ information to monitor the threat of grounding.

One can easily understand that the VDE-SAT is a perfect tool when considering the Arctic sea, which is far from any coastal infrastructure. However, even when the region of interest if close to the coast and possibly equipped with a VDES terrestrial station, the relevant data required for a safe navigation shall be available prior to the arrival to the dangerous area, typically 48 to 72 hours (TBC) in advance, that is to say out of the VHF range of this actual terrestrial station, which makes the use of VDE-SAT essential.



Figure 6: Ex. AMSA/Torres Strait where under keel clearance information is essential for safe navigation.

* + 1. **Automated or on event ship reporting**

Another relevant use case of the VDE-SAT for mariners is related to ship reporting. This reporting may be mandatory, collaborative or of specific interest. For example, IMO has published guidelines for setting up a single window system in maritime transport in order to reduce the administrative burden and facilitate the coordination between the stakeholders. In particular, it includes a reporting requirements for ship visiting foreign ports, 96 hours the pre-entry (IMO Fal forms). Before entering into the terrestrial VDES coverage, a ship pushes its report via the VDE-SAT to the relevant authority. An encryption is applied to protect sensitive data. Similarly, the procedures in place for reporting fish catching may be applied.

Some possible collaborative contribution of high seas trips reporting can be pointed out. One concerns the Voluntary Observing Ship (VOS) program in which ships regularly report weather. The record and data transmission is completely automatic without any manual operation. That kind of in-situ inputs is of crucial interest for the weather forecast in open oceans but not only moreover considering that the network of permanent weather stations tend to decrease. With easy ECDIS menus and standard message formats, the mariner will also be in position to report new dangers at sea, route status or extreme navigation conditions that may be collected by ship in the vicinity, by the shore but also the VDES satellites extending the possible benefit to a large area and other relevant maritime actors.

* + 1. **VDE-SAT opportunity for small vessels fleet or developing areas**

The VDE-SAT is also an opportunity for small ships that are not equipped with expensive cost communication means. A miniaturized AIS class B receiver completed with some functions like the VDES Application Specific Messages (ASM) uplink and the VDE-SAT downlink reception may provide significant added values for a large number of fishermen of developing areas (South East Asia, Africa... [maybe preferable not to list them?]). They will be able to receive warnings/alerts preventing the risks induced by tsunamis or typhoons... In addition, the fishermen will be able to send a message to call for a technical assistance in case they are faced to technical incident like an engine failure or a problem on the helm control.

The VDE-SAT may also be the solution for developing countries to broadcast specific information to ships that navigate on their EEZ. That will be available independently to the implementation and maintenance of a terrestrial dedicated network.

* + 1. **Anti-piracy**
    2. **VDES infrastructure for developing areas**
    3. **High seas communications to small vessels, i.e. fishing vessels**
    4. **Ice chart distribution**

1. **Interoperability with the terrestrial VDES** 
   1. **Resource sharing method for VDES terrestrial and satellite services**

The VDES resource assignment between the VDES terrestrial and the satellite services is outlined in Annex 6 of Rec. ITU-R M.2092. In particular the signaling and control mechanisms envisaged to coordinate the use of each time slot either for terrestrial or satellite communication.

Shore stations utilize terrestrial bulletin board (TBB) and announcement signalling channels (ASC) to coordinate the resource assignment within the control area. The shore station may incorporate information regarding VDE satellite communications within the TBB and ASC. The shore station may acquire the VDE satellite information directly from the VDE-Satellite downlink (the satellite bulletin board and ASC) or in coordination with the satellite service providers.

There are dedicated slots and frequency bands for TBB and ASC that are reserved to communicate the required information to each vessel in the control area of a shore station.

Each satellite system will use bulletin board and announcement channels (as defined in Annex 4 of Rec. ITU-R M.2092) to communicate the VDE-SAT resource assignments (both downlink and uplink) to vessels in the coverage area.

There are dedicated slots and frequency bands for the satellite bulletin board and announcement channels that are reserved to communicate the required information to each vessel in the field of view of a satellite.

Since the satellite coverage may include several shore station control areas, the VDE-SAT resource assignment should respect all requirements of shore control areas that are within the field of view at any given time. Within each satellite orbit the information regarding the resource assignment should be updated according to the shore station control areas in the satellite field of view.

* 1. **Resource sharing between multiple VDES satellite systems**

The sharing of VDE-SAT between two or more satellite systems is envisaged in Rec. ITU-R M.2092 by means of signaling that can be implemented in the Bulletin Board and announcement channel. The bulletin board, transmitted frequently on the VDE-SAT Downlink (channels 2026 and 2086), provides the as a minimum:

* Satellite and constellation ID;
* Satellite ephemeris;
* Downlink communication characteristics: spreading code (if any), time slots for broadcast, time slots for other communications, volume of data to downlink;
* Uplink communication characteristics: spreading code (if any), available time slots for interrogation, available time slots for uplink, global communication channel load, etc.

By listening the bulletin board (transmitted every minute), the ships can determine:

* If a satellite is visible, and identify the satellite
* When it will be visible again (thanks to ephemeris)
* What transmission characteristics (Doppler and delay, thanks to ephemeris)
* When it may initiate a communication for uplink or downlink of data, and globally in which part of the frame this initiated communication will take place.

The physical channel used for the bulletin board should allow for detection of overlapping signals received from multiple satellites. The use of direct sequence spreading as defined in Annex 4 (PL-Frame format 1) of Rec. ITU-R M.2092 allows for detection of up to 8 overlapping signal.

The waveform defintion for VDE-SAT transmission as defined in Rec. ITU-R M.2092 Annex 4 allows sharing different time slots for different VDE-DAT downlink services.

The transmission timing of all VDES components (i.e. AIS, ASM, VDE-SAT and VDE terrestrial), is defined based on a common frame structure that is synchronized in time on the earth’s surface to the UTC. This will allow multiple satellite systems to coordinate the transmission of data services in a time sharing manner within common coverage areas.

1. **Interference to incumbent services and those in adjacent frequency bands**
   1. **Maritime Distress and voice services (see Report ITU-R M.2371)**

The impact of introducing VDE-SAT services into channels 24, 84, 25, 85, 26 and 86 of RR Appendix 18 was addressed in Report ITU-R M2371, along with introduction of terrestrial VDES in channel 24, 84, 25 and 85 of RR Appendix 18.

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, VDE-SAT uplink will not create any additional interference to maritime distress and voice services.

The VDE-SAT downlink is located in the upper leg channels of RR Appendix 18, while maritime distress services and ship-to-ship and ship-to-shore voice is located in the lower leg channels. The 4.6MHz frequency separation between VDE-SAT downlink and these services ensure that they can be protected from harmful interference.

* 1. **Satellite AIS**

The impact of introducing VDE-SAT services into channels 24, 84, 25, 85, 26 and 86 of RR Appendix 18 was addressed in Report ITU-R M2371, along with introduction of terrestrial VDES in channel 24, 84, 25 and 85 of RR Appendix 18.

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, VDE-SAT uplink will not create any additional interference to satellite AIS.

The impact of the VDE-SAT transmission on the AIS1, AIS2, ASM1, ASM2 and LR-AIS reception by satellite has been highlighted in Report ITU-R M2371. Due to a large frequency separation between VDE-SAT transmission frequencies and LR-AIS frequencies, there is no impact on the satellite detection of LR-AIS is expected. The impact of VDE-SAT transmission on the reception of AIS1, AIS2 and ASM1 and ASM2 depends on the system scenarios.

In a system scenario where the VDE-SAT transmission and SAT-AIS reception are hosted on different satellite the space separation between the satellite orbits and their coverage can reduce the impact. In this case, when the two satellite happen to have the same coverage, the use of bulletin boards and the announcement channels as specified in Rec. ITU-R M.2092, provides a practical solution to coordinate and control the duty cycle of the VDE-SAT transmission. Using this mechanism, system operators can schedule the VDE-SAT transmission on a dynamic manner (with a repetitive control as frequent as every minute) to avoid the interference of the VDE-SAT on the detection of SAT-AIS.

The co-location of SAT-AIS receiver and VDE-SAT transmission would require more sophisticated solution on board of the satellite such as full-duplex radio design that would allow for the cancellation of interference caused by the transmitted signal. This may impact the complexity of the on-board transceivers. The use of bulletin board could an effective way to announce to the vessels in the coverage area the envisaged VDE-SAT transmission activities.

* 1. **Radiolocation in the 154-156 MHz band (Russia + others)**

Article 5.225A of ITU radio Regulations states the possible use of frequency band 154-156 MHz for radiolocation services by several administrations on a primary basis. It should be noted that the long-range AIS detection via satellite already received frequency allocation at 157.775 and 157.825 MHz which are closer in frequency to the Radiolocation frequency bands than those of the VDE-SAT uplink (occupying channel 1024, 1084, 1025, 1085, 1026 and 1086). Therefore, the impact of the VDE-SAT uplink detection by satellite especially in high seas where the service is required the most is less severe. Cares must be taken in the design of the satellite to allow proper isolation of out-of-band interference.

The impact of the VDE-SAT transmission on the radiolocation services is expected to be insignificant due to the frequency separation and out-of-band transmission constraints already imposed on the VDE-SAT transmission due to stringent radio astronomy services protection requirements in the 150.05-153 MHz band.

* 1. **Broadcast in the 162-164 MHz band (Morocco) (Liaison note from WP5B required)**
  2. **Space-to-earth in the 162-164 Hz band (China)**
  3. **Fixed services in band (Liaison note from WP5B required)**
  4. **Land and aeronautical mobile services in-band and in adjacent frequency bands (154-164 MHz)(Liaison note from WP5B required)**

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore it will not create any additional interference to land and aeronautical mobile services.

The VDE-SAT downlink has been imposed a pfd mask, as specified in Recommendation ITU-R M.2092-0, which was coordinated and agreed between all relevant ITU Study Groups. This pfd mask ensures that VDE-SAT downlink will not cause harmful interference to land and aeronautical mobile services.

* 1. **PFD limit calculations, averaging time, polarization, required signal characteristics**

1. **Satellite receiver resilience to harmful interference from incumbent services and those in adjacent frequency band**
   1. **Propagation model**
   2. **Link budget simulations based on noise measurements**
   3. **Performance degradation estimates**

The 154 to 156 MHz band has allocations to radiolocation services. Recommendation ITU-R M.1802 specifies the characteristics of these systems. Key figures derived from the characteristics of radar type A and B is provided in Table 1.

Table 1: Key figures derived from the characteristics of radar type A and B as specified in Recommendation ITU-R M.1802.

|  |  |  |
| --- | --- | --- |
| Parameter | Radar type A | Radar type B |
| EIRP at the horizon [dB W] | 55 | 55 |
| Number of horizontal beams | 138.46 | 69.23 |
| Number of vertical beams | 26.15 | 26.15 |
| Number of beams | 3 588 | 1 794 |
| Probability of beam transmission | 8.97 × 10−5 | 1.79 × 10−4 |
| Beam dwell time [ms] | 40.37 | 9.94 |
| Beam revisit time [s] | 144.86 | 17.83 |

Assuming that only one of the beams will be in the direction of the test ship, potential blocking will occur for 13 ms every 145 s or 3.2 ms every 18 s or with a probability of less than 0.02 %. This is insignificant relative to the expected symbol error rate caused by noise. Administrations where the 154 to 156 MHz band has allocations to radiolocation services are all at least 2 000 km away from the test area. The radar signal free space attenuation is then 142 dB, resulting in an antenna signal level of −55 dBm at 154 to 156 MHz. This is well within the expected blocking performance of the VDES receiver RF front-end to be used.

1. **Identification of spectrum requirements and rationale for the use of the frequency bands of Appendix 18 of the RR**
   1. **Potential use of the frequency band 160.975-161.475 MHz versus 2024/2084/2025/2085/2026/2086 for satellite downlink**
   2. **Frequency plan analysis**
      1. **Analysis FDMA, TDMA, CDMA**
      2. **In-band PFD mask**
      3. **Adjacent Radio Astronomy mask**
   3. **Conclusions (primary/secondary)**
2. **Testing, demonstrations and measurements**
3. **Future demonstrations and measurements**
   1. **Norsat-2 (ESA VDE-SAT downlink verification planned H1 2017)**

The objective of the ESA VDE-SAT Downlink Verification is to demonstrate the feasibility of the VHF data exchange via satellite in a real operating environment. The feasibility of VDE-SAT will be demonstrated by a test campaign as well as a VDE-SAT service demonstration.

The main purpose of the test campaign is to assess the performance of the waveforms considered, enabling standardisation of a suitable set of waveforms and corresponding parameters. Based on these results, recommendations regarding the downlink physical layer will be given.

Two test receivers, one on-board a Norwegian Coast Guard vessel and a reference receiver at FFI premises at Kjeller (Norway) will be used during the test campaign. The Coast Guard vessel will receive VDE-SAT transmissions at sea. The terminal at the FFI premises will be used as reference, for transmitter (Tx) and ship terminal receiver (Rx) verification, and debugging if necessary.

The specification and performance figures are derived from the Recommendation ITU-R M.2092-0. The activity shall demonstrate the functionality and performance of VDE-SAT Downlink waveforms and data link protocols that are curently being consolidated by international working groups in IALA and ITU for data exchange via satellite in VHF maritime bands.

* 1. **Uplink measurements campaigns?**
  2. **Global spectrum sweeps for interference mapping?**
  3. **Two-way test/demo VDE-SAT system including protocols?**
  4. **Efficiensea 2 coordination**

EfficienSea2 is a European Community project for a safer and more efficient waterborne operation through new technologies and smarter traffic management. This project which is planned for a 3 year period from mid-2015 to mid-2018 is in the scope of the Horizon 2020, the biggest EU Research and Innovation programme. Lead by the DMA, 33 entities are contributors. One of activities is dedicated to novel maritime communications and among them the VDES. Taking into account the radio technical standards and specifications under construction at IALA and the resolution adopted in November 2015 by ITU during the WRC15, the first initiative to develop VDES hardware prototypes in a lab environment will be lead. In addition, live sea trials are planned for testing exchanges of ship-to-ship and ship-to-shore data with real-life e-navigation scenarios. EfficienSea 2 also intend to coordinate the terrestrial VDES activities with satellite VDES activities that are fortunately also envisaged during the same period of time. They are lead by ESA under the ARTES program dedicated to research on the telecommunications systems. One of these activities is focussed on the VDE-SAT user needs and requirements to derive the system design. Another is aimed at the realisation of a test satellite with a flight demonstration within the EfficienSea 2 timeframe (Figure 6). A liaison between ESA, the main actors of the VDE-SAT activities and the EfficienSea 2 terrestrial VDES actors will permit to include the satellite VDES downlink component into the testbeds.

* 1. **Other test-satellites planned?**
  2. **Norsat-2 and other satellites sharing?**

1. **Technical description for VDE-SAT**
   1. **Technical characteristics of the VDE-SAT Downlink in the VHF Maritime Mobil band (new/updated Annex to Rec. ITU-R M.2092)** 
      1. **Antenna noise levels on-board ships**
   2. **Technical characteristics of the VDE-SAT Uplink in the VHF Maritime Mobil band (new/update Annex to Rec. ITU-R M.2092)**