IALA ENAV Committee
Working Document

IALA VDES WG3

Working document

Source: ~~Haugli~~

~~Affiliation: NCA~~IALA

Annex 5

Technical characteristics of VDES-satellite uplink in the maritime mobile band

~~10~~ 22 April 2015 v1.~~0~~1

1. Structure of the VDES

This Annex describes the characteristics of the satellite uplink of the VHF Data Exchange System (VDES).

The following types of ~~services are described~~functionality are envisaged:

Two-Way:

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- Shore initiated polling of information from ships

- Ship initiated enquiry for information from shore

- Ship initiated data transfer to shore

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Transmit Only:

- Collection of information from transmit only VDES-terminals. This could be either event driven or periodic. (only a limited time assignment and frequency allocation)

- ~~Ship originated single packet data transfer~~
- ~~Ship originated multi-packet data transfer~~

2. OSI Layers (could be moved to Annex 1)

This Annex describes the four lower layers of the OSI model; the physical, the link, the network and the transport layers as shown in Figure 1.

Application layer
Presentation layer
Session layer
Transport layer
Network layer
Link layer
Physical layer

Figure 1. Seven layer OSI model

2.1 Responsibilities of the OSI layers for preparing VDE data for transmission

2.1.1 Transport layer

This layer ensures reliable transmission of the data segments between a ship and a satellite, including segmentation, acknowledgement and multiplexing.

2.1.2 Network layer

This layer is responsible for the management of priority assignments of messages, distribution of transmission packets between channels, and data link congestion resolution.

2.1.3 Link layer

This layer ensures reliable transmission of data frames between a satellite and a ship.

The link layer is divided into three sub-layers with the following tasks:

2.1.3.1 Link management entity

Assemble unique word, format header, pilot tones, subframe headers and VDES message bits into packets.

2.1.3.2 Data link services

Applies bit stuffing, calculates and adds CRC check sum and completes the subframe/packet.

2.1.3.3 Media Access Control

Provides methods for granting data transfer access. Both random access and assigned access are used.

2.1.4 Physical layer.

This layer provides transmission and reception of raw bit streams over a physical medium.

3. Physical layer **(Only in Annex 4, to be removed from here)**

3.1 Range (minimum and maximum)

The orbit height determines the satellite range variations. For a 600 km LEO the maximum range is 2830 km. The minimum range is the orbit height.

For timing purposes a maximum range of 3000 km shall be used. The minimum range shall be 300 km. The path delay will therefore vary from 10 ms to 1 ms, a variation of 9 ms as shown in Figure 2.

Need to consider higher orbits

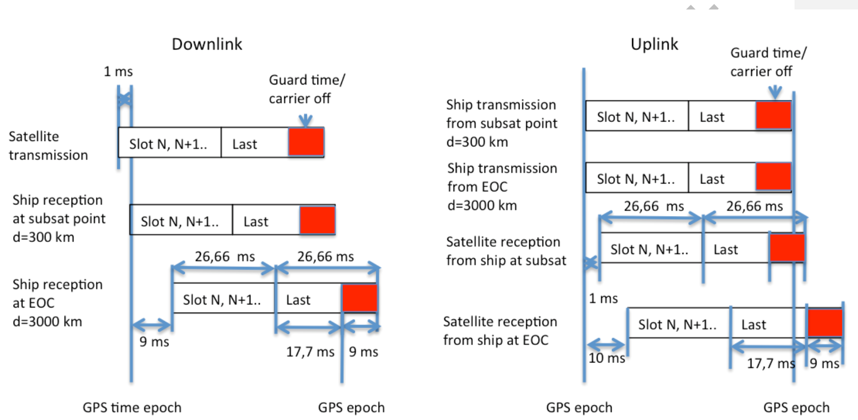

Figure 2. Downlink and uplink slot timing

(Source: Haugli, Space Norway)

3.2 Frequency error

The frequency error is the sum of the satellite transmission frequency error and Doppler. The transmit frequency error at the satellite shall be less than 2 ppm TBC, i.e. +/- 320 Hz.

A small LEO satellite will move at a speed of about 8 km/s and this will cause a maximum Doppler of +/- 4 kHz at VHF.

3.3 Uplink nominal link budget

The link C/N_0 is determined by the ship EIRP, path losses, propagation losses, satellite G/T and interference levels.

3.3.1 Ship transmit power

The saturated transmit power from a ship is the same as for AIS, i.e 12,5 W and this power level is used for fixed envelope modulation methods such as CW, BPSK, QPSK and 8PSK. For non-constant envelope such as 16APSK and filtered signals the baseline transmit power is 6 W linear.

A lower transmit power close to saturation could be envisaged (nominal saturated power below 1 W).

3.3.2 Transmit antenna gain

(If there is any other input we will input it here, otherwise we refer to Annex 4 with the exact picture).

Existing ship antennas shall be used for VDES. The maximum antenna gain for these range from 2 to 10 dBi. Representative antenna patterns are shown in Figure 3.

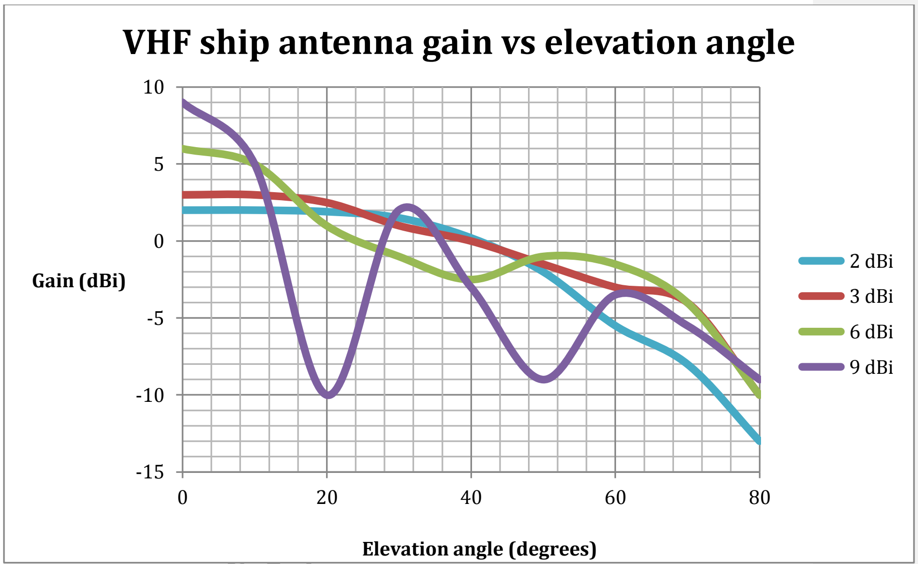

Figure 3. Ship antenna gain vs. elevation angle.

(Source: Haugli, Space Norway, derived from Comrod datasheets)

3.3.3 Ship EIRP vs elevation angle

The minimum ship EIRP vs elevation angle is shown in Table 1. There are no minimum EIRP requirements above 80 degrees elevation. Table 1 is based on a linear transmitter meeting the maximum Adjacent Channel Interference levels defined in the subframe format tables. For saturated operation the EIRP shall be 3 dB higher.

Table 1. Minimum ship EIRP vs. elevation angle (iso C/N0)

Ship elevation angle	Min. antenna gain with 6 W transmitter	Minimum ship EIRP
degrees	dBi	dBW
0	1,5	9,26
10	-1,8	5,95
20	-4,7	3,1
30	-6,7	1,06
40	-7,5	0,24
50	-7,4	0,36

60	-6,5	1,32
70	-4,2	3,58
80	-1,7	6,11
90	1,5	(9,29)

3.3.4 Satellite antenna gain

The worst case linkbudget occurs at 0 degrees ship elevation angles and the highest satellite antenna gain should be in this direction.

A suitable antenna is a crossed 3 element Yagi with a peak gain of 8 dBi. The satellite antenna gain vs. ship elevation angle is shown in Table 2.

Commented [NA1]: Alternative could be AIS dipole. If there is any input we may include that here.

Table 2. Satellite antenna gain vs. ship elevation angle (Source: Haugli, Space Norway)

Ship elevation angle	Nadir offset angle	Boresight offset angle	Satellite antenna gain
deg.	deg.	deg.	dBi
0	66,1	0	8
10	64,2	1,9	8
20	59,2	6,9	8
30	52,3	13,8	7,8
40	44,4	21,7	6,9
50	36	30,1	5,5
60	27,2	38,9	3,6
70	18,2	47,9	0,7
80	9,1	57	-2,2
90	0	66,1	-5,5

3.3.5 Satellite system noise temperature

The satellite noise level at the receiver input is shown in Table 3. Without external interference the system noise temperature is 25.7 dBK.

Table 3. Satellite receiver system noise temperature

Antenna noise temperature	200,0	K
Feed losses	1,0	dB
LNA noise figure	2,0	dB
LNA noise temperature	159,7	K
Feedloss noise temp. at LNA	56,1	K
Antenna noise temp. at LNA	158,9	K
System noise temp. at LNA	374,7	K
System noise temp. at LNA	25,7	dBK

3.3.6 Uplink C/N0

The baseline uplink linkbudget is given in Table 4. It is optimised for 0 degree ship elevation angles and the ship minimum EIRP is reduced at higher elevation angles to achieve a constant C/N0 of 70 dBHz for all elevation angles up to 80 degrees.
For most elevation angles the ship EIRP will be higher than the minimum, and C/N0 up to 10 dB higher may be expected. It is not envisaged that VDES will use uplink power control.

Table 4. Baseline uplink link budget.

Ship elevation angle	Ship miniumum EIRP	Polarisation and propagation losses	Range	Pathloss	Satellite G/T	C/N0
deg	dBW	dB	km	dB	dB/K	dBHz
0,0	9,7	6,0	2830,0	144,6	-17,7	70,0
10,0	6,3	6,0	1932,0	141,3	-17,7	70,0
20,0	3,5	6,0	1392,0	138,4	-17,7	70,0
30,0	1,5	6,0	1075,0	136,2	-17,9	70,0
40,0	0,6	6,0	882,0	134,4	-18,8	70,0
50,0	0,8	6,0	761,0	133,2	-20,2	70,0
60,0	1,7	6,0	683,0	132,2	-22,1	70,0
70,0	4,0	6,0	635,0	131,6	-25,0	70,0
80,0	6,5	6,0	608,0	131,2	-27,9	(70,0)
90,0	9,7	6,0	600,0	131,1	-31,2	(70,0)

3.4 Propagation effects

Refer to Annex 4 (only new content will be reported here).

The received signal level on-board a ship will vary due to a number of causes. A Rice distribution with a Carrier to Multipath (C/M) ratio of 10 dB and fading bandwidth of 3 Hz is assumed, however the system shall be adaptable to handle significantly worse and better propagation conditions.

Table 5. Ionospheric effects for elevation angles of about 30° one-way traversal

(Source: Gallinaro, Space Engineering, derived from Recommendation ITU-R P.531)

Effect	Frequency dependence	0.1 GHz	0.25 GHz	1 GHz
Faraday rotation	$1/f^2$	30 rotations	4.8 rotations	108°
Propagation delay	$1/f^2$	25 μs	4 μs	0.25 μs
Refraction	$1/f^2$	< 1°	< 0.16°	< 0.6′
Variation in the direction of arrival (r.m.s.)	$1/f^2$	20′	3.2′	12″
Absorption (auroral and/or polar cap)	$\approx 1/f^2$	5 dB	0.8 dB	0.05 dB
Absorption (mid-latitude)	$1/f^2$	< 1 dB	< 0.16 dB	< 0.01 dB
Dispersion	$1/f^3$	0.4 ps/Hz	0.026 ps/Hz	0.0004 ps/Hz
Scintillation (1)	See Rec. ITU-R.P.531	See Rec. ITU-R P.531	See Rec. ITU-R P.531	>20 dB peak-to-peak

* This estimate is based on a TEC of 1018 electrons/m², which is a high value of TEC encountered at low latitudes in day-time with high solar activity.

(1) Values observed near the geomagnetic equator during the early night-time hours (local time) at equinox under conditions of high sunspot number.

Table 6. Mid-latitude fade depths due to ionospheric scintillation (dB)

Percentage of time (%)	Frequency (GHz)			
	0.1	0.2	0.5	1
1.0	5.9	1.5	0.2	0.1
0.5	9.3	2.3	0.4	0.1
0.2	16.6	4.2	0.7	0.2
0.1	25.0	6.2	1.0	0.3

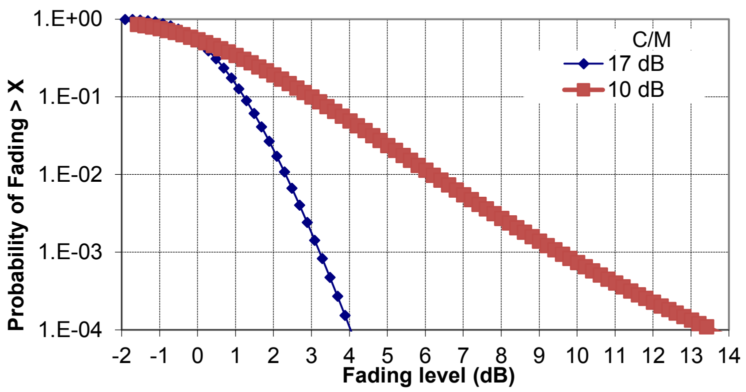

Figure 4. Ricean fade depth probability

(Source: Gallinaro, Space Engineering)

3.5 Modulation

VDES uses adaptive modulation and coding to maximise spectral efficiency and throughput. The supported modulation methods are given in Table 7.

Table 7. Downlink modulation methods

Index	Bits/symbol	Modulation type	Bit mapping	Maximum adjacent channel interference level with worst case Doppler
		BPSK or CPM		
1	2	Grey encoded QPSK	Fig. 5	- 18 dB
2	3	Grey encoded 8PSK	Fig. 6	- 18 dB
3	4	16APSK	Fig. 7	- 18 dB

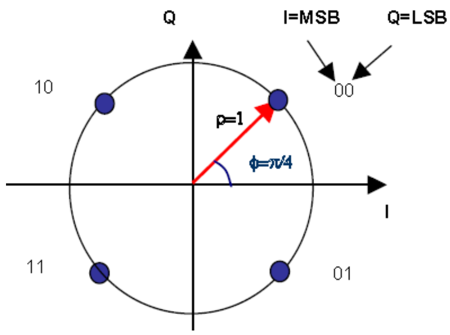

Figure 5. QPSK symbol to bit mapping

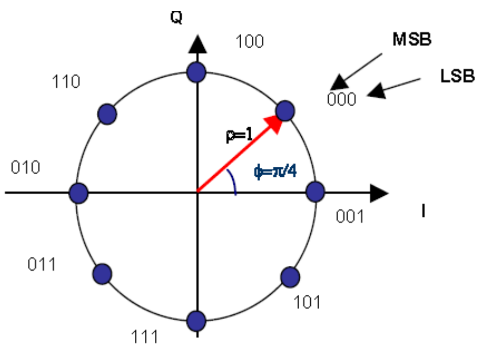

Figure 6. 8PSK symbol to bit mapping

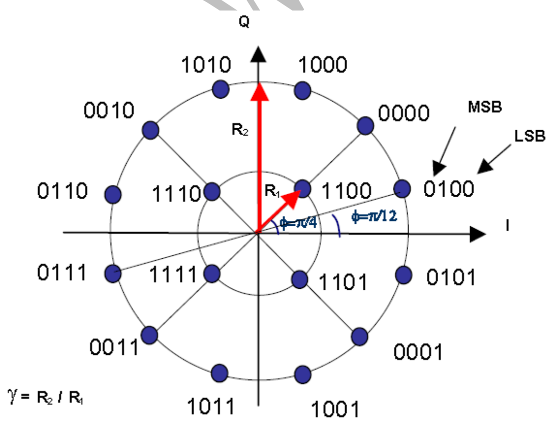

Figure 7. 16APSK symbol to bit mapping

The 16APSK modulation constellation shall be composed of two concentric rings of uniformly spaced 4 and 12 PSK points, respectively in the inner ring of radius R_1 and outer ring of radius R_2.

The ratio of the outer circle radius to the inner circle radius ($\gamma = R_2/R_1$) shall be equal to 3. R_1 shall be set to $1/\sqrt{7}$, R_2 shall be set to $3/\sqrt{7}$ in order to have the average signal energy equal to 1.

3.6 Symbol timing accuracy
~20 ppm TBC

3.7 Transmitter Timing Jitter
<5% rms TBC

3.8 Slot Transmission Accuracy
+/- 100 micro sec TBC

3.9 Half duplex and full duplex satellites
To be referred to Annex 4.

The system can be configured for both half and full duplex satellites as shown in Figure 8.

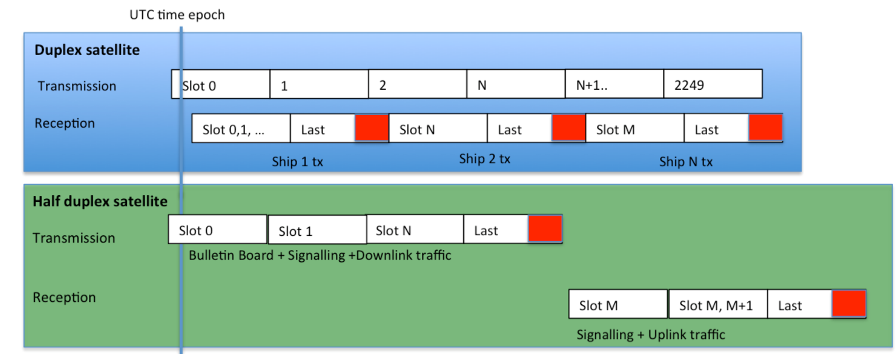

Figure 8. Half and full duplex satellite operation
(Source: Haugli, Space Norway)

3.10 Uplink frame hierarchy
Open Points:
1) Guard Time (do we need it to dela with the variable propagation delay?)
2) We use 1 or more slots for uplink
3) The bandwidth and the centre frequency will be part of the Sub-frame format
4) Announcement channel will be used for assigning capacity (ASC), updates to Annex 4 if needed.
5)

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The VDES frame structure is identical and synchronized in time on the earths surface to UTC (as in AIS) and the frame hierarchy for a subframe of N slots is shown in Figure 9. Each element is described in the subsequent sections. Frame 0 starts at 00:00:00 UTC, and there are 1440 frames in a day.

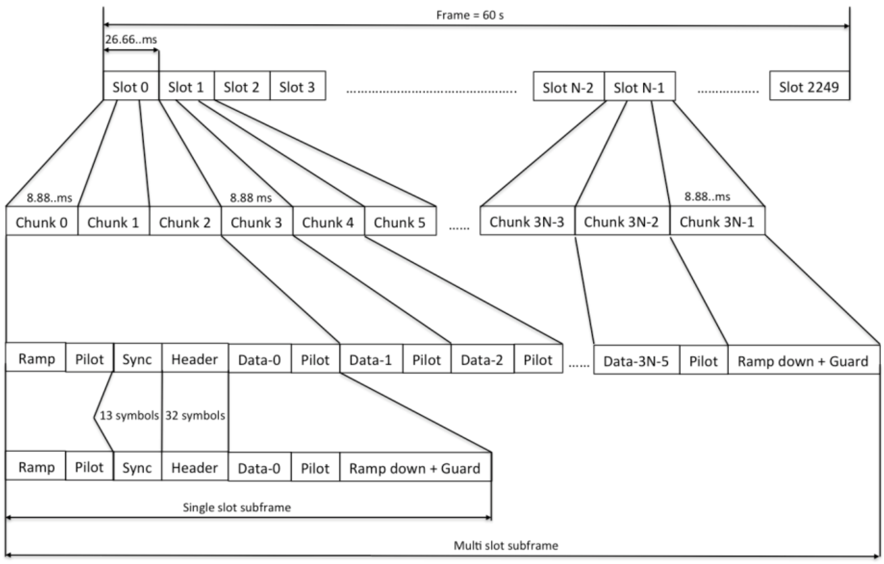

Figure 9. VDES uplink frame hierarchy (draft) **(updated to remove the sub-sub segments)**
(Source: Haugli, Space Norway)

3.10.1 Guard time and ramp up

The ramp up time from 10% to 90% of the power shall occur in less than 3~~1~~00 uS.

The guard time at the beginning of a subframe may not be required, but has been provided to allow for future expansion of the pilot, synchronisation word and the subframe format header.

3.10.2 Synchronisation pilot

This CW (before scrambling) signal before the synchronisation word and after every ~~data chunk~~burst has a fixed duration of x ms.

3.10.3 Synchronization word

(keep in mind the impact of interference in order to define the length of pilot, sync and (known header).

The subframe synchronisation word and header format is fixed for all transmissions. The 13 bit Barker code unique word is defined in Table 8. It is modulated with BPSK at a symbol rate of x kbps. Bit 0 is transmitted first.

Table 8. Barker sequence unique word

Bit number												
0	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1

3.10.4 Direct Sequence Spreading

The BPSK symbols are spread using a 8 bit sequence to a chiprate of 21 kcps to fit in a 50 kHz channel. Spreading sequence SS0 from Table 9 is used.

Table 9. Spreading sequences TBC

Sequence name	Chip number							
	0	1	2	3	4	5	6	7
SS0	-1	-1	-1	1	1	-1	1	1
SS1	-1	-1	1	-1	1	1	1	-1
SS2	-1	1	-1	1	1	1	-1	-1
SS3	-1	1	-1	-1	-1	-1	1	-1

Commented [NA2]: Update according to the input from Thibaud)

3.10.5 Subframe header (7 bits)

This could be known a priori (via bulletin board on the downlink).

To look at the right mapping to get a good correlation property for most used sequence.

The header is BPSK modulated and spread the same way as the synchronisation word described above. This header defines the following characteristics for the remainder of the subframe:

- Subframe duration
- Number of data chunks
- Symbol rate
- Modulation type
- FEC type
- FEC rate
- Interleaver type
- Scrambler type (if used)
- Spreading code length (if used)
- Spreading codes (if used)

The header provides 7 bits to define up 128 subframe formats and uses (32,7) quad orthogonal forward error correction coding. The performance of this FEC is shown in Figure 11.

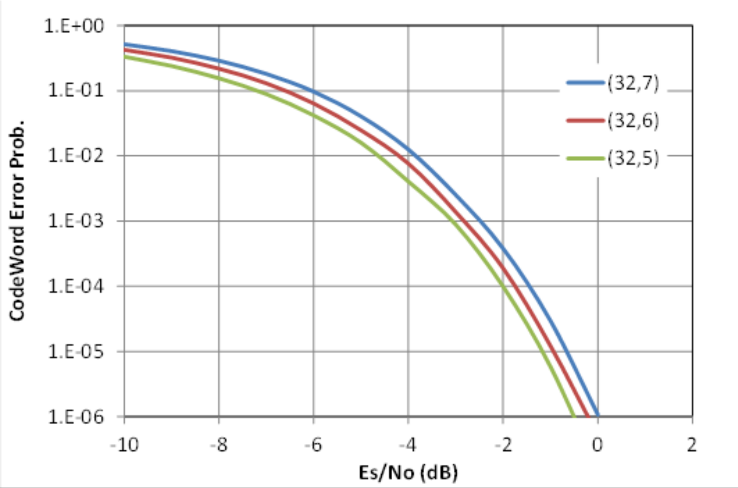

Figure 11. Header error probability
(Source: Gallinaro, Space Engineering)

Commented [NA3]: May need to be updated for the uplink C/N0+I0.

3.10.6 Data-N

Segment N ~~of interleaved dat~~is encoded one burst at a time,~~a~~.

3.10.7 Ramp down

The ramp down time from 90% to 10% of the power shall occur in less than 100 uS.

3.10.8 Guard time

No transmissions shall occur during the guardtime to avoid partly overlap with terrestrial AIS/VDES slots. The guard time is 8.9 ms.

Commented [NA4]: To be reviewed. This is a big hit on the overhead.

3.10.9 Subframe format

(Examples of packet types to be mapped to each format ACK, NACK. Capacity Request).

The following formats are envisaged:

- CDMA random access short subframe (x~~4~~ slots) To be determined depending on the minimum message size per transmission. (minimum message bits 100 bits), Question on the interference level .
- CDMA random access medium length subframe (y~~25~~ slots)
- TDMA random access/TDM single slot subframe (Action to compare ACRDA and E-SSA to make a decision).
- DAMA: TDM assigned medium length subframe(25 slots) Decide on the minimum duration to deal with the Ricean fading.

These formats are defined in Tables 10.1 to 10.~~4~~ 3(4) (to be added)

4. Link layer

4.1 Data encapsulation
A subframe consist of multiple variable length datagrams and these are encapsulated. Each datagram contain the following encapsulation fields:

- Datagram type (1 byte)
- Datagram size (3 bytes)
- ~~Terrestrial service type (1 byte, optional)~~
- Datagram sequence number (2 bytes, for multi-segment datagrams)
- Source ID (8 bytes, optional)
- Datagram payload (variable)
- Data padding (variable, less than 8 bits)
- CRC (4 bytes)

(Action HCH: To provide some packet definitions especially for short packets to assess the overhead)

4.2 Cyclic Redundancy Check

The 32 bit ITU polynom 0x04C11DB7 CRC is appended to the last segment of the datagram. The CRC is calculated over all segments.

F(x)= x32 + x26 + x23 + x22 + x16 + x12 + x11 + x10 + x8 + x7 + x5 + x4 + x2 + x + 1

Initial state: 0xFFFF

4.3 Automatic repeat request (ARQ)
Single slot format with a payload
Datagrams may or may not use ARQ, this is defined for each datagram type. An ARQ will request retransmission of a specific lost datagram segment.

4.4. Acknowledgement (ACK)

All datagrams without CRC errors are acknowledged over the satellite link.

4.5 End delivery notification (EDN)

All datagrams successfully delivered to the destination will be notified to the source.

4.5 End delivery failure (EDF)

All datagrams not successfully delivered within the timeout or retry limit will be notified to the source.

4.6 Physical and Logical channels

VDES uses several channels to carry data. These channels are separated into Physical and Logical Channels. The satellite transmits a Bulletin Board that defines the configuration of these channels.

4.7 Physical Channels

The Physical Channels (PC) are determined by the center frequency, subframe format and start timeslot.

4.8 Logical Channels (LC)

The logical channels are divided into signalling and data channels. These are described below.

4.9 Signalling Logical Channels (or bursts?)

The following uplink signalling channels are used:

- Random access resource request
- Announcement response
- Acknowledgement
- Automatic repeat request

4.9.1 Random access resource request (RQSC)

A ship uses this channel to access the network. This channel is a pure Aloha channel. A ship will randomly select the transmission time within the slots allocated for this channel on the Bulletin Board.
The request includes a downlink C/N0 estimate and message size.

4.9.2 Announcement response channel (ARSC)

A ship uses this channel to inform the satellite that it is ready to receive a message. The response includes a downlink C/N0 estimate.

4.9.3 Acknowledgement (ACSC)

A ship uses this channel to inform the satellite that it has received a message correctly (CRC match).

4.9.4 Automatic repeat request (ARQSC)

A ship uses this channel to inform the satellite that it has not receive a message correctly (CRC failure). The ship can request retransmission of the whole message or up to 4 fragments. The acknowledgement includes a downlink C/N0 estimate.

4.10 Data Logical Channels

The following data channels are used:

- Random access short messages
- Assigned data transfer

4.10.1Random access short messaging (RADC)

This channel is used for short messages that fit in a single transmission

4.10.2 Assigned data transfer (ADDC)

This channel is assigned by the satellite following a resource request from a ship. It is intended for longer messages and is optimised for throughput.

5. Network layer

5.1 Uplink data transfer protocols

The following protocols shall be supported:

- Ship originated single packet data transfer
- Ship originated multi-packet data transfer

The protocols are shown in Figures 12 and 13.

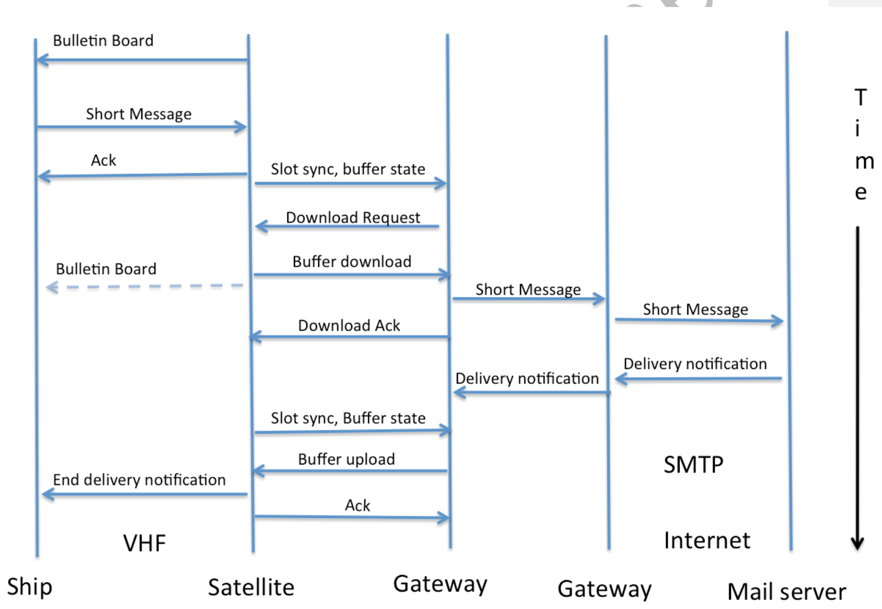

Figure 12. Ship originated single packet data transfer (draft)

(Source: Haugli, Space Norway) update the figure, add:

1) Annuncment channel
2) To be random access

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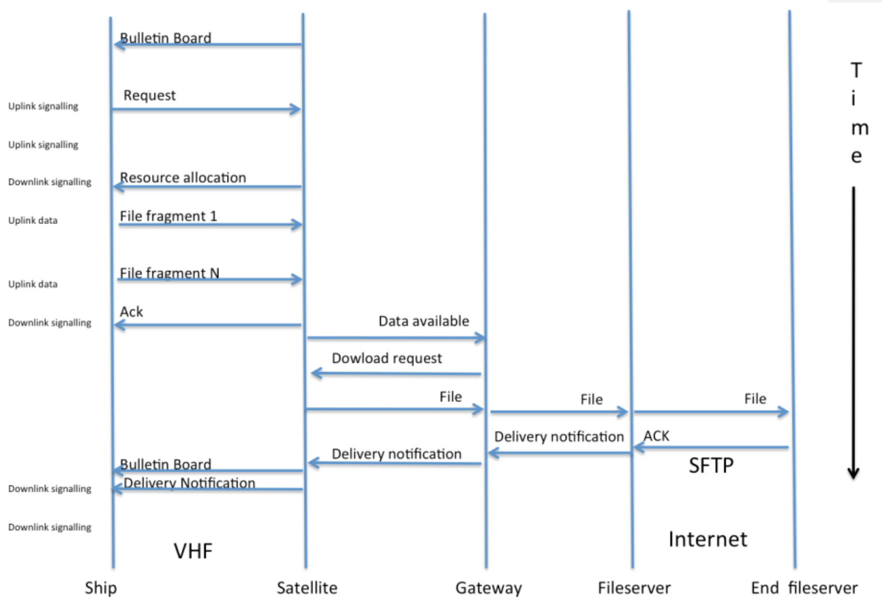

Figure 13. Ship originated multi-packet data transfer (draft) To be reviewed (applicable to DAMA)

(Source: Haugli, Space Norway)

The figure should include: time slot and non-exclusive bands.

Figure 14. Ship originated Transmit Only Protocol (No ACK), Random Access

6. Transport layer

Reference to Annex 3

6.1 ~~End to end protocols~~