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ICAO Technical Manual enhancements recommended by the VDL Mode 4 Enhancement Group (VEEG)

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Introduction

The VDL Mode 4 Enhancement and Evaluation Group (VEEG) is a group established by EUROCONTROL and LFV. The purpose of the group has been to propose and evaluate enhancements to the VDL Mode 4 system. The group has held regular meetings in the last year under the chairmanship of Eurocontrol.

The emphasis so far has been on broadcast functionality and one of the main activities has been to use Eurocontrol's simulation tool of VDL Mode 4, the VDL Mode 4 Performance Simulator (VPS), to evaluate changes to the protocol and parameters. VPS is a full fidelity simulation of the VDL Mode 4 protocols.

A detailed report on the work of the VEEG will be available soon. Meanwhile, the purpose of this note is to describe briefly a number of enhancements investigated by VEEG and to present a set of recommended changes to the VDL Mode 4 ICAO Technical Manual.

Summary of enhancements

The investigations used as a baseline the Core Europe traffic scenario for 2010 and investigated performance when each aircraft transmits 4 times per minute. This results in a channel loading of approximately 140%. This baseline is intended as one channel in a four channel scenario providing total transmission rates of 16 per minute per aircraft. It should be noted that the performance of more highly loaded channels was also assessed and the results will be presented in the VEEG report.

A range of enhancements were investigated. Of these the following resulted in significant performance improvement.

Modification of Slot conflict quality of service parameters. The VEEG work demonstrated that a change to the quality of service parameters listed in Table 1-91 of the Technical Manual results in an increase of the operational range of the system. The key observation is that although slot selection may result in sharing of slots in subsequent superframes, very often an aircraft whose slot is being "stolen" is in a position to detect the conflict and select a better slot. In the current system, the slot conflict parameters only force conflict resolution when aircraft are closer than 75 nmi. Taking account of the CCI performance, this results in a system that "accepts" an operational range equal to a quarter of 75 nmi (ie less than 20 nmi). In fact, by changing the slot conflict parameters to 360 nmi, the slot conflict procedures are invoked more often and act so as to try to increase the operational range to 90 nmi. The overall impact of this enhancement was to produce a substantial increase in the operational range of the baseline scenario. The VEEG concluded that this enhancement was high priority and should be incorporated into the Technical Manual.

Respecting potentially reserved slots. This was known as "***enhancement B***" during the VEEG work. In the current slot selection algorithm, level 0 selections include both free slots and "garbled" slots where there is at least one transmission but the station has not been able to decode it. Observation of the baseline scenario shows that once a slot becomes garbled, the slot selection algorithms act to make it more garbled. However, when a slot is garbled on a channel where the majority of reservations are made by the periodic broadcast protocol, it is highly likely that the garbled slot contains reservation information leading to "potential reservations" in subsequent superframes. The VEEG investigated the impact of only selecting from free slots at level 0 and then considering potential reservations at a later stage in the slot selection algorithm. A significant increase in operational range was obtained and the VEEG concluded that an appropriate change should be recommended for the Technical Manual. The differentiation between free and garbled slots makes use of slot occupancy detection already provided in the Technical Manual. This regards a slot as free if the received power is less than a nominal level referred to as the noise floor (the slot is regarded as "unoccupied"). Since it is possible that some slots may have low level transmissions which lie below the noise floor, the Technical Manual change assigns potential reservations to both unoccupied and occupied slots. Potential reservations associated with unoccupied slots are selected first at level 0. Potential reservations associated with occupied slots are then considered at a later stage in the algorithm. In both cases, priority is given in increasing order of the signal level received in the unoccupied or occupied slot which gave rise to the potential reservation.

Geographical division of the slot map. This was know as "***enhancement A***" during the VEEG work. Analysis of the baseline scenario demonstrated that a significant proportion of shared slots result from pairs of aircraft that are out of line of sight of each other. Such shared slots result in decreased operational range for aircraft, generally high up in the scenario, that are in line of sight of both aircraft. During the VEEG, a proposal was made for how to control the slot selection by these "hidden terminals": it involved restricting the slot selections

made by aircraft in a particular geographical region to a particular range of slots in the slot map. It was shown that a scheme could be derived that allowed an aircraft to choose from the correct area of the slot map by reference to its position in a CPR patch. The enhancement produced an increase in operational range but it was noted by VEEG that a similar effect could be produced by the use of ground control (a facility already in the Technical Manual requiring the support of ground stations). Hence no detailed change is recommended. However, it was decided that appropriate hooks should be added to the Technical Manual so that this enhancement could be added later as part of revised ADS-B procedures. This takes the form of a note clarifying that the user, when specifying candidate slots for selection, can exclude certain slots from the candidate range.

Variable power transmissions. This was known as "***enhancement D***" during the VEEG work. Operational requirements for different classes of transmitter are defined in RTCA ADS-B MASPs (DO-242A). VPS was used to assess the impact of grouping the traffic scenario into operating classes A0, A1, A2 and A3 and assigning different powers to the classes according to the desired operating range. It was concluded that a useful trade-off was produced involving a reduced but satisfactory operating range for lower power classes and an increased operating range for higher power classes. VEEG noted that the definition of variable power transmitter classes can be accommodated within the transmission power range providing in VDL SARPS. The detailed class definitions can be provided within MOPS. Hence no changes to the Technical Manual were recommended.

Other VEEG conclusions and recommendations. The analysis of the simulation results both for the 140% baseline scenario and for channel loads up to 542% concluded that the only one stage of slot selection was performed for the periodic broadcast protocol. Hence the second stage defined in the Technical Manual is not needed. It was therefore recommended that, for clarity of presentation, the text describing the first stage be removed and the second stage set with quality of service parameters equivalent to the old first stage. Further analysis of the simulation results demonstrated that, on occasion, periodic streams became interrupted with the loss of the occasional transmission. The source of this was traced to the behaviour of the slot conflict procedure for the periodic broadcast protocol. A modification to the technical manual was proposed, simulated and shown to provide a small increase in performance.

Summary of proposed changes to the Technical Manual

The proposed changes to the Technical Manual are:

a change in the default QoS for slot conflict to the value simulated in the VEEG work and shown to provide significant benefit in terms of operational range. A default value of 360nmi was chosen so as to be 4 times 90nmi (a good operational range for VDL4 in high density areas as required in MASPS). Note that this value can be changed by the user if required.

a modification of the slot selection procedure for the periodic broadcast protocol to remove consideration of potentially reserved slots from the first stage of slot selection. The modification uses the slot occupied requirement already present in the TM (section 1.2.4.3) to detect that a slot contains more than one transmission. An additional section 1.2.4.4 is added to provide an indication of signal level. The reservation table text (1.3.6.1) is modified to introduce the concept of "potential reservations". The periodic broadcast procedure in 1.3.10.5.2 is then modified as follows: The application of levels 0 to 2 excludes potential reservations associated with occupied slots. Prior to proceeding to level 3, slots containing potential reservations associated with occupied slots are then added in. As written, the text replicates the simulated enhancement B and produces useful performance gains.

simplification of the two stage sync burst selection process to a single stage through the removal of Table 1-19 and associated text. Note that the QoS parameters for selection of slots have been modified to be 20 nmi more than the QoS for conflict resolution. This change has been made to make selections at level 2 consistent with the desired operational range (90nm) and to provide a small element of hysteresis preventing the case where slot selection immediately invokes slot conflict resolution procedures (ie if A selects a slot used by B, a mobile at distance 360nm, then if B is moving towards A, it will need to invoke the slot conflict procedures – this is unnecessary and made less likely by setting the slot selection parameters for A slightly higher than the conflict resolution parameters).

modification of the slot conflict procedures for periodic broadcast to prevent interruption of a periodic stream. (note that it appears at least one manufacturer has implemented it this way anyway)

minor modification of random access procedures for delayed transmissions to remove a small inconsistency between the definition of channel busy in section 1.2.4.2 and its usage in 1.3.7.2.2.

since VEEG investigations showed benefits from implementing enhancement A, a "hook" for the later addition of this enhancement is provided in section 1.3.6.2.1 as a note clarifying that the user can

exclude certain slots for selection within the candidate range. Note that it is assumed that, with the proposed addition, geographical mapping of the slot map can be achieved as an extension to the ADS-B procedures in chapter 3.

VEEG work has also shown that setting transmitter power according to class can be a useful way of tuning performance. No TM changes are necessary to provide this. It is assumed that it is a MOPS issue.

Proposed changes to the Technical Manual (red-line text)

1.2.1 MAC sublayer services

Note.— The MAC sublayer provides

a) TDMA media access;

b) time synchronization of the start of each time slot in the channel (Section 1.2.3);

c) transmission (Section 1.2.5) and reception (Section 1.2.6) processing.

The MAC sublayer shall accept from the physical layer a continuous indication of channel idle/busy status and signal level (see Section 1.2.4). The MAC sublayer shall accept from the VSS sublayer a burst for transmission, accompanied by the time to transmit it. The MAC sublayer shall provide to the VSS sublayer the received burst data, slot busy/idle status, slot occupancy status, signal level, and the status of bursts sent for transmission.

1.2.4.3 Slot occupied detection

A slot shall be considered occupied if the channel is considered to be continuously busy for a period of at least 5 msec during the slot.

Note.— The slot occupied detection is used to monitor the operations of peer stations~~, including the L1 counter~~ and to provide an indication that there might be transmissions in a slot even if those transmissions cannot be decoded by the MAC layer. This is different from the channel idle/busy state, which affects in part the station's ability to make a random transmission.

1.2.4.4 Signal level indication

The MAC sublayer shall accept from the physical layer an indication of the signal level.

Note.- The signal level indication is used in the periodic broadcast protocol as defined in Section 1.3.10.5.2. The measurement is for relative purposes only and need not be calibrated to any standard.

1.3.6.1 Reservation table

A station shall maintain a table of all reservations in the next 4*M1 + 128 slots. For each reserved slot, the reservation Table entry shall consist of the 27-bit address of the intended transmitter, the 27-bit address of the destination (if any) and the type of reservation made. For periodic broadcast reservations (see Section 1.3.10) and directed request reservations (see Section 1.3.16), the reservation table shall also include pointers to all other reserved slots associated with the same reservation stream.

For the periodic broadcast protocol (see Section 1.3.10), the reservation table shall also record potential reservations, defined as the M1, 2 M1, 3 M1 and 4 M1 slots after a slot for which no transmission has been decoded by the MAC layer. For each potential reservation, the reservation table shall include the signal level (see Section 1.2.4.4) associated with the slot and the occupancy status as defined in Section 1.2.4.3. Slots containing both potential reservations and reservations resulting from decoded transmissions, shall be treated as if containing reservations from the decoded transmissions only.

Note 1.- Since the slot is treated as only containing a decoded transmission, any potential reservations in subsequent superframes are effectively erased.

The reservation table shall be updated before the end of the first slot after the end of the burst.

With the exception of delayed bursts (see Sections 1.2.5, 1.5.5.3.3.1 and 1.5.5.3.4), and cases where a station has been directed to transmit by another station, a station shall wait for at least M1+128 slots after starting to listen to a channel before starting to transmit or reserve slots.

Note ~~1~~2.— This allows sufficient time to build up the reservation table data.

Note ~~2~~3.— A reservation table is for specification purposes only and the implementer is free to choose the method by which the reservation information is stored and processed. A station is required to record all reservations for a slot for possible use in slot selection algorithms because several stations may intentionally share a slot.

Note ~~3~~4.— There may be more than one reservation associated with a particular slot.

Note 5.- Potential reservations are associated with any slot for which the MAC has failed to decode a received transmission. Although this implies that such slots may contain a reservation that was not decoded, the slot occupancy algorithm (see Section 1.2.4.3) will mark some of these slots as "likely occupied" and others as "likely unoccupied". The periodic reservation protocol (see section 1.3.10) deals differently with these two classes giving initial priority to potential reservations associated with unoccupied slots.

1.3.6.3.1 Specification of candidate slots

The VSS user shall specify ~~a~~ one or more ranges of candidate slots for slot selection.

Note 1.— The method for specifying candidate slots is protocol dependent (see Sections 1.3.9 to 1.3.18).

Note 2.- In addition to slots excluded because of ground quarantine (see Section 1.3.6.4.1), the VSS user can also specify other slots that should be excluded for the purposes of slot selection. Such slots might be slots that are potentially reserved (see Section 1.2.4.3) or which the VSS user wishes not to be used at all for slot selection.

Table 1-12. Action in the event of reservation conflict

Protocol for A's existing reservation (made by A)	Protocol for B's conflicting reservation	Action by A
Slots reserved by station A using ground quarantine (see Section 1.3.6.4)	Any	Transmit according to existing reservation.
Periodic broadcast	Incremental broadcast, big negative dither unicast request, or information transfer	Transmit according to existing reservation.

Protocol for A's existing reservation (made by A)	Protocol for B's conflicting reservation	Action by A
Periodic broadcast	Periodic broadcast (autonomous/directed), directed request, slots reserved by ground quarantine (see Section 1.3.6.4)	If the conflict occurs later than A's next transmission in the stream, then select a new transmission slot and reduce the value of TV11 so as to cause the stream to dither to the new slot prior to the conflict; otherwise, set TV11 equal to 1 so that A's next transmission causes the stream to dither to a different slot in the next superframe after the superframe in which the conflict first occurs~~do not transmit in the former slot, and re-establish the stream in a new slot~~.
Incremental broadcast or big negative dither	Any	Do not transmit in the existing reservation, and make the transmission in an alternative slot by random access (Section 1.3.7).
Unicast request (sdf = 1),	Any	Do not transmit in the existing reservation, and apply the retransmission procedures (Section 1.3.21).
Information transfer (ACK burst)	Any	Do not transmit in the existing reservation

1.3.7.2.2 Random access procedures for delayed transmissions

Delayed transmissions shall use a p-persistent algorithm as defined below:

a) transmissions shall be delayed relative to the slot boundary in accordance with Section 1.2.5; and

b) a station shall not start a transmission if the channel idle/busy status (see VDL SARPs Section 6.9.5.3) is busy~~, as defined in Section 1.2.4,~~ at the intended (delayed) start time.

If the station is unable to select a slot, this shall be regarded as an unsuccessful random access attempt.

If the station is able to select a slot, then the station shall transmit on the slot boundary with probability p (defined in section 1.3.7.1.2).

1.3.10.5.2 Selection of slots for a periodic broadcast transmission

If there is no existing periodic reservation for the VSS user, the station shall select a current transmission slot (ct_slot) corresponding to each nominal slot by inspection of the reservation table data, using the following procedure:

The station shall use the slot selection procedure specified in Section 1.3.6.2 using all slots that are within truncate((V12/2)*(M1/V11))) of n_slot and within 127 slots of n_slot, as candidate slots and the default or other VSS user supplied quality of service parameters~~the parameter settings defined in Table 1-19~~.

When applying the slot selection procedure specified in Section 1.3.6.2, the station shall first select available slots at levels 0, 1 and 2 excluding slots containing potential reservations associated with occupied slots as defined in Section 1.2.4.3. Selections at level 0 shall select from slots containing potential reservations associated with unoccupied slots in increasing order of signal level as defined in Section 1.2.4.4.

If, on completion of the selection of available slots at level 2, less than Q4 slots have been chosen, the station shall select from slots containing potential reservations associated with occupied slots in increasing order of signal level as defined in Section 1.2.4.4.

If at the end of this process, less than Q4 slots have been chosen, the station shall then continue the slot selection process at level 3.

~~Table 1-19. Periodic broadcast QoS parameters~~

~~Symbol~~	~~Parameter name~~	~~Default~~
~~Q2a~~	~~Slot selection range constraint for level 1~~	~~300 nmi~~
~~Q2b~~	~~Slot selection range constraint for level 2~~	~~300 nmi~~
~~Q2c~~	~~Slot selection range constraint for level 3~~	~~1000 nmi~~
~~Q2d~~	~~Slot selection range constraint for level 4~~	~~1000 nmi~~
~~Q4~~	~~Number of available slots~~	~~3~~

*Note ~~1~~.— The station ~~first~~ tries to find unreserved slots in the range V12 * M1/V11 on either side of the nominal slot ignoring slots that are four superframes after a slot in which a station detects the presence of a transmission but is unable to decode the transmission. The ignored slots are assumed to contain potential reservations since the undecoded transmission is most likely to contain a periodic reservation protocol for subsequent superframes. If slot selection is unsuccessful by the end of level 2, the potential reservations are then added back into the candidate range and selected in order of increasing signal level.*

~~If slot selection is unsuccessful, the station shall re-apply this slot selection, using the same candidate slots and the default or other VSS user supplied quality of service parameters.~~

~~*Note 2. — If the first stage is unsuccessful, the station can use previously reserved slots of the most distant users (assuming that the quality of service parameters supplied by the VSS user allow this).*~~

1.5.5.1 Synchronization burst procedures

All stations shall transmit the appropriate synchronization burst defined in Section 1.5.2 depending on whether it is a mobile station or a ground station. If the synchronisation burst is transmitted with a periodic broadcast protocol ~~and slot selection is unsuccessful using the QoS parameters defined in Table 1-19, the application of~~ slot selection, as defined in Section 1.3.10.5.2, shall use default QoS parameters except as ~~the VSS user supplied QoS parameters~~ defined in Table 1-90. If the synchronisation burst is not transmitted with a periodic broadcast protocol, slot selection shall use the default QoS parameters defined for the selected reservation protocol or user supplied QoS parameters. The values of the subfields shall be the latest available data that can be obtained by the station at the start of the slot ~~immediately~~ that is two slots ~~preceding~~ before the first slot of the intended transmission. Where time is used to calculate fields in the transmission, it shall be the time associated with the latitude and longitude data contained in the transmission.

~~A station transmitting a synchronization burst in a slot assigned by another station shall set the a/d bit to 1; otherwise, the station shall set the a/d bit to 0.~~

Table 1-90. Synchronization burst parameters

Symbol	Parameter name		Default
~~TV11min~~	~~Reservation~~	~~minimum~~	~~4~~
~~TV11max~~	~~Hold timer~~	~~maximum~~	~~8~~
V11	Nominal periodic rate		6
~~V12~~	~~Periodic dither range~~		~~0.1~~
~~V21~~	~~Nominal rate~~		~~100~~
~~V22~~	~~Max Dither range~~		~~31~~
Q1	Priority		~~As per information field~~14
Q2a	Slot selection range constraint for level 1		~~150nmi~~380nmi
Q2b	Slot selection range constraint for level 2		~~150nmi~~380nmi
Q2c	Slot selection range constraint for level 3		0nmi
Q2d	Slot selection range constraint for level 4		~~300nmi~~380nmi
Q3	Replace queued data		TRUE
~~Q4~~	~~Number of available slots~~		~~3~~

1.5.5.1.4 Procedures for conflict resolution

For the purposes of assessing whether another reservation conflicts with a reservation for a synchronization burst, the station shall apply the procedures defined in Section 1.3.6.5. In this case the ~~default~~ quality of service parameters defined in Table 1-91 or user supplied parameters shall be applied to the synchronization burst reservation.

Table 1-91. Synchronization burst parameters for conflict resolution

Symbol	Parameter name	~~Default~~Value
Q1	Priority	As per information field
Q2a	Slot selection range constraint for level 1	360~~150~~nmi
Q2b	Slot selection range constraint for level 2	360~~150~~nmi
Q2c	Slot selection range constraint for level 3	360~~75~~nmi
Q2d	Slot selection range constraint for level 4	~~300nmi~~360nmi

Note.— These ~~default~~ parameters place ~~a~~ tighter constraints ~~at level 3~~ than the defaults for original slot selection, which would always result in a slot being selected. The tighter constraint forces the stream to dither to find slots that might be available at higher levels and hence reduces the probability of slot conflict.