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Assessment of VDL Mode 4 Frequency, Capacity and Performances

TRS041 Deliverable 3:

Capacity Simulations

(Update included)

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Assessment of VDL Mode 4 Frequency, Capacity and Performances

D3: Capacity Simulations

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Abstract

This document is an update of the third deliverable of contract C/1.211/03/JC/TRS041/05 achieved for EUROCONTROL EATM/CND/COE/CNS/COM in Brussels. This document performs:

- Simulations cross-check between ACTS/VDL4 and VPS
- Analysis of VDL4 performance for point-to-point communications, through analysis of simple scenarios as well as more complex (i.e. operational) scenarios (Link 2000+ scenarios).
- Identification of main VDL4 characteristics and parameters that are impacting VDL4 performance and potential standard enhancements.

Keywords

VDL Mode 4	Cross-Check	System Capacity	VDL2/VDL4 comparison
VPS	ACTS/VDL4	System Performance	CPDLC
ATC	AOC	Future System	

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DOCUMENT CHANGE RECORD

The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
1.0	02-May-2006	First circulated release.	All
1.1	09-July-2006	Updates made according to VDL4 workshop held May 11th and 12th, 2006. Corresponding action items are given between brackets.	
		[A11] Clarification in the two simulators' differences when generating data messages.	Appendix C.3
		[A12, A14] Appendix added to document ACTS/VDL4 supported features.	Appendix G
		[A15] Clarify simulations made against "Time Critical Requirements".	Section 4.2
		[A16] Added text to explain why the 2-steps slot-selection process, that proved to be ineffective in cross-check scenarios, is also ineffective in the Link2000+ like scenario.	Section 4.3
		Add clarifications about ATC data profile and document preliminary results on priority management when running Link2000+ scenario.	Section 4.3
		Appendix added to provide a detailed description of output statistics that ACTS/VDL4 and VPS have in common.	Appendix F
2.0	28-Dec-2009	Incorporates additional simulation and results achieved in 2007-2009 according to suggestions made by LFV (change in recommended parameter set).	Section 4.2 Section 4.3 Appendix C.5
3.0	16-July-2010	New Large Scale Static Scenario (scenario description; simulation outputs; observations)	Section 2.1.3 Section 2.2.3 Section 2.3.3
3.1	3-Sept-2010	Updated according to VM4C + Eurocontrol comments agreed on August 17th, 2010	All

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1. INTRODUCTION

1.1 Background on VDL 4 analysis at Eurocontrol

EUROCONTROL has carried out several studies about air/ground communications subnetworks covering interference, frequency planning and capacity aspects for several of them.

Two main VHF data-link sub-networks have been studied in depth:

- VDL Mode 2, that currently is deployed to replace POA ('Plain Old ACARS') and to support CPDLC services in the framework of Link2000+ program; and
- VDL Mode 4, promoted as a complementary candidate for VDL Mode 2 for point-to-point applications (also candidate for supporting ADS-B as an alternative to Mode S).

1.1.1 VHF Interference investigations

Frequency planning criteria

VDL Mode 2 -Frequency planning criteria were developed in ICAO Working Group B between 1998 and 2001 and were accepted in September 2001 in agreement with the main contributions made by EUROCONTROL [10].

VDL Mode 4 -Frequency planning criteria development has been initiated in the same period in ICAO ACP WG-B. The group opted for the same methodology [3] and defined interference assessment criteria adequate for VDL Mode 4. Unfortunately, the first testing campaign in 2002 revealed reception performance problem on the single available VDL Mode 4 airborne radio used for these tests. Therefore assessing a realistic frequency planning based on these measurements was not possible.

The same manufacturer's modified airborne equipment has been used in the new testing campaign in March 2005 again. However the overall results did not differ much from those obtained in 2002. The critical test case that had been observed in 2002 has been observed again; it appeared that this was due to a premature saturation of the receiver. A repetition of the same tests with a VDL4 ground radio from a different manufacturer yielded better results roughly comparable with those achieved in the VDL2 tests.

The saturation problem has been identified and resolved in a new airborne equipment release in September 2005 prior to testing that radio again, contacts had been made with several avionics radio manufacturers but in December 2005, none additional had been made available to EUROCONTROL.[1]

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[1] The avionics radio tested is made by CNS. ADSI, RTX and Rockwell Collins were contacted in first semester of 2005.

Airborne Co-Site Interferences

EUROCONTROL has completed several studies addressing interference issue in the VHF band over the last few years. When frequency planning criteria has been established for VDL Mode 2 [10], ICAO ACP WG-B has requested Airborne co-site interferences to and from VDL Mode 2 also to be analysed [12] . Therefore the same subject had been opened also when frequency planning criteria development has been started for VDL 4 within ICAO WG-B [3].

Airborne co-site interference case is the most stringent case to be addressed when evaluating VDL compatibility with other onboard existing VHF systems (within 108-137MHz). As a matter of fact, antenna isolations are poor due to the short antenna separation distances on the aircraft, and transmission powers in use need to be high enough to provide a wide range of operation, although it potentially conflicts with the uplink VHF voice or data signals to be correctly and independently decoded.

In 2003, a “VDL Mode 4 Airborne Architecture Study” [4], [5] has analysed the theoretical impact of VHF co-site interference in general and showed that detailed and practical investigations were necessary to proceed further.

VDL Mode 4 is foreseen to support a large field of applications including ADS-B and point-to-point communications, and is intended also for supporting ‘time-critical applications’. In support of these applications, investigations about interference to VDL Mode 4 and their impact on VDL 4 capabilities become crucial.

Other VHF systems currently used in the air traffic context need to be protected against the potential interference of VDL Mode 4. It is the case of DSB-AM voice which will remain safety critical for years, but also VDL 2 which is the first data-link generation able of fulfilling other ATC requirements (in the case of coexistence of VDL Mode 2 and Mode 4 on the same platform/aircraft).

The first phase of VDL 4 Co Site interference Impact Investigation including “co site scenario” and “detailed test description“ has been achieved in 2004 by ISA Telecoms on behalf of EUROCONTROL [8], [9].

1.1.2 System capacity studies through simulations

Previous VDL4 simulation campaigns have been conducted by Helios Technology on behalf of EUROCONTROL.

The first campaign has been conducted in 2002 to address the VDL4 capacity in support of ADS-B broadcast applications.

The second campaign has been conducted, completing in 2005 [6] to address the VDL4 capacity in support to point-to-point communications. Refering to criteria of CoopATS [19] and Macondo [18] available at the time, the campaign demonstrated that, as currently specified in ICAO standards [1], the VDL4 technology was unsuitable to support time-critical and/or safety critical applications. Having identified some of the protocol issues, the campaign investigated potential protocol enhancements [6]. Changes were recommended by Helios Technology in several potential directions (optimisation of re-transmission parameters, ground-coordination development, sectored antennas,..) Although some capacity improvements were expected, the identified enhancements were still requiring additional validation before proceeding with submission to ICAO for endorsement.

End 2005, EUROCONTROL contracted ALTYS Technologies for additional simulations, both to confirm previous results, and to proceed further with the evaluation of the technology if it was to be deployed and used in Europe in support to ATC communications. A first set of conclusions were presented to the community in a workshop held in May 2006 in EUROCONTROL premises.

Following the workshop, and to further investigate potential enhancements, EUROCONTROL pursued the analysis, coordinating with VM4C[2] members about most desirable and acceptable enhancements. This document is the synthesis of such complementary assessments, all conducted between 2005 and mid-2009.

1.2 Study Objectives

The objectives of the previous VDL Mode 4 study (2005 and 2006) were as follows:

- Pursue and complete co-site interferences investigations initiated in 2003;
- Complete the VDL Mode 4 interference testing to contribute to ICAO ACP WG –B on planning criteria
- Validate and complement previous system capacity assessment campaigns in support of time-critical and safety-critical applications[3].

To achieve the above, the study has been structured around three Work Packages:

- WP1 – Project Management
- WP2 – Interferences investigations with a deliverable D2 reporting on Frequency Planning Criteria and Airborne Cosite interference assessment.
- WP3 – Simulators Cross-check and Capacity Assessment by use of Simulations, with a deliverable D3 reporting on VDL 4 capacity.

The objectives of latest VDL Mode 4 study (up to 2009) were, in coordination with VM4C, to further investigate and assess VM4C identified enhancements. In practice, recommended changes dealt with changes in VDL4 System Parameters, to supersede default values defined in ICAO SARPS (cf. [1]).

Additional activities have thus been conducted:

- Validation of ACTS/VDL4 physical model through theoretical and cross-check simulations;

[2] The members from the VDL Mode 4 Community (VM4C) that have actively participated in this study are LFV and Helios Technology Ltd.

[3] Although such exercise might be valuable as well, the present study has no objectives with respect to the validation of previous system capacity assessment campaigns in support of broadcast applications.

- Reassessment of co-site interferences (see updated D2).
- Rerun of capacity simulations based on VM4C provided parameter set (see updated D3 (present document); section 4.3, using revised Parameter Set PS4 defined in Appendix C.5).

1.3 Present Deliverable Objectives

The present deliverable documents the results and findings of the “Simulators Cross-check and Capacity Assessment by use of Simulations” (WP3) of the above mentioned contract.

The main objectives of WP3 are:

- Perform cross-validation of VPS and ACTS.
- Conduct further capacity simulations.
- Investigate some potential VDL4 enhancements and their benefits for capacity and performance.

To achieve the above, the following sub-tasks were identified and conducted:

- **Task 3.1 – Simulation Cross-check**

  Define and run scenarios with both VPS and ACTS simulators. Analyse the produced results. Explain the differences.

- **Task 3.2 – Advanced Simulations**

  Use ACTS to rerun most significant cross-check simulations under realistic conditions (in terms of propagation model, dynamic air traffic, link-management, co-site interferences; etc.). Analyse differences with task 3.1 results.

- **Task 3.3 – LINK 2000+ scenarios**

  Use ACTS to assess VDL4 capability to provide support to LINK 2000+ type scenarios (point-to-point communications only).

- **Task 3.4 – VDL4 enhancement identification**

  Identify and characterises enhancements to be brought to the current ICAO VDL4 specification.

1.4 Document Structure

Section 2 documents cross-check scenarios between VPS and ACTS/VDL4 simulators.

Section 3 provides cross-check scenario updates to assess the potential impact of Link Management, more accurate propagation model (large-scale fading) and co-site interferences.

Section 4 positions VDL 4 performance for time-critical applications, and in comparison with VDL Mode 2 for simple scenarios and for supporting Link2000+ traffic.

Section 5 analyses the VDL Mode 4 main weaknesses and identifies potential areas of improvement.

Section 6 summarizes and concludes the present deliverable.

2. SIMULATION CROSS-CHECK (STATIC SCENARII)

2.1 Scenario Definitions

A complete cross-check exercise between two simulators requires first to:

- Identify all simulators-specific behaviours
- Define an adequate set of air traffic to be commonly simulated
- Define an adequate set of associated data traffic also to be commonly simulated
- Define an adequate set of common VDL4 system parameters

The outputs of such preliminary activity are fully detailed in Appendix C and Appendix D. Built upon the above, the cross-check campaign has been organised into two phases:

- Simplistic scenario
- Medium static scenario
- Large scale static scenario

As explained in Appendix C, taking into account the features available only in ACTS-simulator (e.g. air traffic movements, large scale fading included in the propagation model, etc.), for the 'Advanced' simulations, only one simulator has been available.

The large scale static scenario, initially not specified in first phase of present study (i.e. as of 2006), was completed under a work plan agreed during 2007 between Eurocontrol and VM4C to extend the simple and medium scale cross-check simulations. It also used a revised system parameter set, PS4, following additional work carried out by VM4C [24] to identify a parameter set more performant than SARPS' default one (see [1]), to the large Scale Static Scenario.

2.1.1 Simplistic Scenarios

They are called as such because they involve simplified communications not really corresponding to an operational situation; these scenarios focus on a limited aspect of point-to-point transmissions at a time (short or long procedure, uplink or downlink, various network loads).

They provide the following main benefits:

- They are straightforward to run (a few seconds are generally required)
- Simulation results can be compared directly to theoretical values (as an independent reference)
- They provide preliminary cross-check results (provided that both simulators comply to theoretical values – see previous point).

The following scenarios have been defined:

Cross-check Scenario	Station Locations	Data Traffic	Parameter Set	2-steps burst selection (simulator feature)	Objectives
CS-0.1.1[4]	SL1	DT-ds1.10	PS0	OFF	Short procedures (1-slot) Downlink only, at various rates Single link (1 aircraft) (queuing effect on the DLE)
CS-0.1.2		DT-ds1.15			
CS-0.1.3		DT-ds1.20			
CS-0.1.4		DT-ds1.25			
CS-0.2.1	SL1	DT-us2.10	PS0	OFF	Short procedures (2-slots) Uplink only, at various rates Single link (1 aircraft) (queuing effect on the DLE)
CS-0.2.2		DT-us2.15			
CS-0.2.3		DT-us2.20			
CS-0.2.4		DT-us2.25			
CS-0.3.1	SL1	DT-ul4.10	PS0	OFF	Long procedures (4-slots) Uplink only, at various rates Single link (queuing effect on the DLE)
CS-0.3.2		DT-ul4.15			
CS-0.3.3		DT-ul4.20			
CS-0.3.4		DT-ul4.25			
CS-0.4.1	SL2	DT-us1.1	PS0	OFF	Short procedures (1-slot) Uplink only, at various rates Multiple links (100 aircraft) (queuing effect on the VSS)
CS-0.4.2		DT-us1.3			
CS-0.4.3		DT-us1.4			
CS-0.4.4		DT-us1.5			
CS-0.5.1	SL2	DT-ds1.1	PS0	OFF	Short procedures (1-slot) Downlink only, at various rates Multiple links (100) (collisions due to random selection)
CS-0.5.2		DT-ds1.2			
CS-0.5.3		DT-ds1.4			
CS-0.5.4		DT-ds1.6			

Table 1 – Simplistic Cross-check Scenarios

2.1.2 Medium Scale Static Scenarii

The following scenarios have been identified. They are made of:

- A common set of mobile and fixed stations locations (400 aircraft, 10 Ground Stations).
- A common data traffic (32 octets uplink and downlink; 0.5 message per minute)

[4] Bold scenarios last 10 hours (simulated duration)

Cross-check Scenario	Station Locations	Data Traffic	Parameter Set	2-steps burst selection (simulator feature)	Objectives
CS-1.1.1	SL3	DT-B1	PS1	OFF	Medium-Scale scenarios (low data traffic)
CS-1.1.2				ON	
CS-1.2.1			PS2	OFF	
CS-1.2.2				ON	
CS-1.3.1			PS3	OFF	
CS-1.3.2				ON	
CS-2.1.1	SL4	DT-B2	PS1	OFF	Large Scale scenarios (low data traffic)
CS-2.1.2				ON	
CS-2.2.1			PS2	OFF	
CS-2.2.2				ON	
CS-2.3.1			PS3	OFF	
CS-2.3.2				ON	

Table 2 – Medium and Large-Scale Cross-check Scenarios

2.1.3 Large Scale Static Scenario

Under a work plan agreed during 2007 between EUROCONTROL and VM4C to extend the original cross-check simulations, a single large-scale static scenario was defined with a high communication load. The scenario uses the revised system parameter Set PS4.

The scenario is detailed in Appendix D – “Large Scale Static Scenario for simulation cross-check”.

2.2 Simulation Results for cross-check scenarios.

2.2.1 Simplistic Scenarios

Cross-check Scenario	Transit delays (i.e. one-way delays)						Round-trip delays (i.e. two-way delays)						Success Rate	
	Avg. (s)		Std. Dev. (s)		On time 5s (%)		Avg. (s)		Std. Dev. (s)		On time 8s (%)		(%)	
	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS
CS-0.1.1	0.31	0.31	0.66	0.49	99.5	100	1.78	1.75	1.09	0.84	99.8	100	100	100
CS-0.1.2	0.68	0.50	1.53	0.77	96.6	99.76	2.16	1.99	2.50	1.02	98.0	100	100	100
CS-0.1.3	9.39	0.77	16.65	1.07	58.2	97.31	10.86	2.22	17.54	1.28	61.6	100	100	100
CS-0.1.4	256	1.12	321	1.47	0.7	97.20	307.9	2.61	353.2	1.65	0.7	98.74	83.4	99.75
CS-0.2.1	0.33	0.32	0.70	0.48	99.5	99.82	1.78	1.73	1.16	0.87	99.8	100	100	100
CS-0.2.2	0.71	0.52	1.77	0.78	96.6	99.57	2.17	1.94	2.66	1.04	97.9	99.36	100	100
CS-0.2.3	28.0	0.82	40.9	1.18	35.5	98.73	29.49	2.27	41.91	1.39	37.3	99.23	100	100
CS-0.2.4	236.7	1.54	302.8	1.87	0.5	93.80	288.5	3.04	334.6	1.99	0.8	97.14	82.4	99.88
CS-0.3.1	3.9	4.39	3.94	1.94	79.9	68.00	5.38	5.84	5.46	2.06	91.3	85.30	100	99.50
CS-0.3.2	5.135	8.55	5.7	8.33	59.2	27.65	6.61	10.07	7.11	8.38	76.0	43.89	100	99.77
CS-0.3.3	54.35	133.29	74	79.71	4.4	0.00	55.9	134.79	75.7	79.74	7.4	0.01	99.86	90.3
CS-0.3.4	277	373.37	363	206.87	0.3	0.00	347	374.85	406	206.88	0.3	0.002	80.3	75.31
CS-0.4.1	0.18	0.27	0.21	0.48	100	99.89	1.62	1.83	0.72	0.98	100	99.89	100	99.93
CS-0.4.2	0.38	0.92	0.42	1.26	99.97	98.14	1.85	2.72	1.94	1.79	100	97.92	100	99.83
CS-0.4.3	0.92	176.22	1.19	141.33	99.51	2.7	2.41	179.50	2.61	144.45	99.8	3.01	100	93.21
CS-0.4.4	10.72	494.70	11.5	307.01	3.7	0.65	12.2	498.01	12.9	307.12	10.2	0.84	99.62	71.27
CS-0.5.1	0.23	0.27	0.65	0.55	99.5	99.53	1.69	1.75	0.94	0.91	99.8	99.62	100	99.65
CS-0.5.2	0.36	0.36	1.0	0.74	98.7	99.63	1.83	1.84	2.03	1.03	99.6	99.84	99.98	99.93
CS-0.5.3	0.81	0.65	2.0	1.22	95.0	98.39	2.28	2.15	3.01	1.41	97.8	99.27	99.95	99.90
CS-0.5.4	1.48	1.02	3.2	1.66	88.9	8.05	2.96	2.51	4.19	1.78	93.6	8.23	99.89	8.38

Table 3 – Cross-check results for Simplistic Scenarios

2.2.2 Medium Scale Static Scenarios

Cross-check Scenario	Transit delays (i.e. one-way delays) Avg. (s)		Std. Dev. (s)		On time (%)		Round-trip delays (i.e. two-way delays) Avg. (s)		Std. Dev. (s)		On time (%)		Success Rate (%)	
	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS	ACTS	VPS
CS-1.1.1	0.65	2.82	1.82	2.72	95.36	81.67	2.22	4.36	3.03	2.85	96.96	88.97	99.21	99.42
CS-1.1.2	0.64	2.82	1.85	2.74	95.60	82.39	2.21	4.36	3.03	2.87	97.00	89.00	99.36	99.63
CS-1.2.1	0.54	0.75	1.32	0.69	98.52	99.56	0.82	1.01	1.57	0.73	99.03	99.70	99.89	99.71
CS-1.2.2	0.52	0.75	1.26	0.69	98.61	99.69	0.79	1.01	1.51	0.72	99.24	99.86	99.92	99.87
CS-1.3.1	0.41	0.69	1.23	0.95	98.65	99.02	0.69	0.96	1.47	1.00	99.15	99.76	99.84	99.90
CS-1.3.2	0.41	0.67	1.23	0.88	98.60	99.20	0.69	0.94	1.46	0.93	99.12	99.74	99.77	99.90

Table 4 – Cross-check results for Medium-Scale Scenarios

2.2.3 Large Scale Static Scenario

			Unit	VPS U	VPS D	VPS Total	ACTS / VDL4 U	ACTS / VDL4 D	ACTS / VDL4 Total
Physical	Offered Load	(G)	%	54.27	44.9	99.17	69.88	58.66	128.54
			Kbits/s	10.42	8.62	19.04	13.42	11.26	24.68
	Throughput	(S)	%	20.99	17.76	38.75	25.1	23.04	48.14
			Kbits/s	4.03	3.41	7.44	4.82	4.42	9.24
	Rates	Requests	Nb	179158	164075	343233	175857	160820	336677
		Success	%	82.51	90.88	86.51	85.86	97.35	91.35
		Co-site victim	%	0	0	0	0	0	0
		Collided	%	Note 1	Note 1	Note 1	22.72	4.42	13.98
	Failures	LOS	%						
		Power	%						
		Co-site	%						
		Collision	%	17.49	9.12	13.49	14.14	2.52	8.59
Link	Transit delay	Average	Ms	1036	1035	1035	1618	1240	1422
	Round Trip delays	Average	Ms	1616	1647	1632	2167	1873	2015
	Handovers (HO)	Total		-	0	0	-	314	314
User	Requests		Nb	62583	67082	129665	62595	66826	129421
	Success		%	97.81	93.72	95.70	98.41	99.28	98.86
	On-time Transit Dly	(< 5s)	%	96.08	92.45	94.20	94.67	98.04	96.41
	On-time Rnd Trip Dly	(< 8s)	%	96.58	92.61	94.53	97.22	98.72	98.00
	Data rate		%						

Table 5 – Cross-check result for Large Scale Static Scenario

Note 1: statistics not available.

2.3 Simulations Cross-Check : Synthesis

2.3.1 Detailed Comparison of the Simplistic Scenarios

The simplistic scenarios are made of 5 series corresponding to 5 basic testing configurations:

- CS-0.1 and CS-0.2 involves short-procedures only (respectively downlink and uplink only) over a unique air-ground link;
- CS-0.3 is similar, but for long-procedures only, on the uplink direction only
- CS-0.4 involves short-transmissions only, on the uplink direction only, at low message rages, over multiple links (100 aircraft)
- CS-0.5 is similar, but for the downlink direction only

Cross-check Scenario	Scenario Objectives	Conformance to Expected Theoretical Results		Main findings
		ACTS	VPS	
CS-0.1.x CS-0.2.x	**Experience DLE saturation with short transmissions only (downlink and uplink)**	**DLE saturation observed at the anticipated message rate (around 20 messages / minutes). Success Rate when DLE saturation is experienced in line with expectation (converging towards 80%: the longer the simulation duration, the better the convergence)**	**Performance results higher than expected due to failure to experience DLE saturation. Investigation shown that the cause is a partial implementation of a technical manual recommendation. In VPS, linkage is limited to M-linked transmissions (i.e. to long-transmissions involving message segmentation only; long transmission not involving segmentation, or short transmissions are excluded from this implementation). As a consequence, PDU linkage is never performed in this series – thus never causing the expected DLE saturation.**	**Considered individually, each simulator provides outputs that are comparable in the downlink (CS-0.1.x series) and uplink (CS-0.2.x) directions – this is consistent with expectations. The two simulators produce comparable results at low message rates (10 and 15 messages / minutes). Because of VPS failure to experience DLE saturation (refer to VPS column), the simulators are no longer comparable when fed with high message rates involving short procedures.**

Cross-check Scenario	Scenario Objectives	Conformance to Expected Theoretical Results		Main findings
		ACTS	VPS	
CS-0.3.x	**Experience DLE saturation with long transmissions only** **(uplink only)**	**DLE saturation experienced at anticipated message rate (around 20 messages / minutes).** **Drop of transit and round-trip delays faster than in the CS-0.1 and CS.0.2 series (as expected).** **Success Rate when DLE saturation is experienced in line with expectation (convergence towards 80% quicker than in previous series).**	**DLE saturation experienced, but sooner than expected (i.e. at a lowest message rate): with on-time transit and round-trip delays of respectively 0.4% and 0.1% the DLE shows a permanent saturation at 20 messages / minutes.** **This again is due to the partial implementation of the recommended DLPDU linkage. Because the linkage doesn't occur in the present simulations, an additional random access time is required for each user-data transmissions (compared to linked transmissions), thus inducing a sooner-than-expected DLE saturation.** **Conclusion on the partial DLPDU-linkage outcome:** **Two opposite effects are possible on simulation results; system performances are boosted when involving short-procedures and decreased with long-procedures.**	**Same as above.** **The explained divergence between the two simulators is appearing even earlier (i.e. at smaller message rates) here – with long-procedures – than with short procedures.**
CS-0.4.x	**Saturation of VSS' random access queue** **(multiple links, uplink only)**	**VSS saturation experienced at anticipated message rate (about 5 messages / minutes).** **Before saturation is experienced, transit and round-trip delays in-line with expectations.** **When saturation is experienced: Success Rate in line with**	**Unexpected and inexplicable low performance results experienced from lowest message rate (the VSS should have no problem at all serving 100 uplink messages per minutes). [ongoing investigation]**	**Inaccurate VPS outputs for scenarios involving short-procedures, multiple links. [ongoing investigation]**

Cross-check Scenario	Scenario Objectives	Conformance to Expected Theoretical Results		Main findings
		ACTS	VPS	
		expectation (still close to 100%).		
CS-0.5.x	**Collisions due to random access (multiple links, downlink only)**	**Transit and round-trip delays significantly higher than theoretical values, as expected. Stable Success Rate around 100% (in conformance to theory).**	**Transit and round-trip delays significantly higher than theoretical values, as expected. Unexpected drop of transit and round-trip delays at 6 messages / minute.**	**Quite comparable results between ACTS and VPS, except at higher message rate (6 messages per minute), where VPS results abruptly decrease. The divergence at the higher message rate may be explained by VPS' partial implementation of the DLPDU linkage recommendation: being limited to M-linked transmissions, linkage is never experienced in that series, generating more random transmissions, thus more collisions, thus lower performance results, than with ACTS (to be confirmed by VPS team). Excepted at higher message rate, VPS is apparently experiencing globally less collisions than ACTS (unexplained behaviour).**

In addition to the above observations: a fluctuation of about ±20% has been observed on two consecutive 1-hour long simulations. All simplistic scenarios have shown the extreme importance of the simulation's duration: the longer the better (produced outputs are quite stable at 10-hours duration).

2.3.2 Medium Scale Scenarii: Detailed Comparison

All medium-scale scenarios are made of

- A common mobile and fixed station location (400 aircraft, 10 Ground Stations).
- A common data traffic (32 octets uplink and downlink; 0.5 message per minute)

They involve three main series – CS-1.1, CS-1.2 and CS-1.3 – each involving a distinct system parameter profile (various set of persistence and slot-selection parameters: V32, V33, V43 through V46). Each series is run with the 2-steps slot-selection process (see appendix C.1.3) turned OFF (inactive in CS-1.y.1) or ON (active in CS-1.y.2).

Cross-check Scenario	Scenario Objectives	Main findings
CS-1.x	**Medium-scale scenario** **(low message rates)**	**Unexpectedly long VPS transit delays (and consequently round-trip delays) in the CS-1.1.x series (which involves a 20,200 slot selection window).** **Except for the CS-1.1.x series, the two simulators have comparable outputs. VPS simulation results are always slightly higher than ACTS results. This might be due to the boosting of expected results for short transmissions already experienced with simplistic scenarios.** **Both simulators lead to conclusion that the 2-steps slot-selection process provides no improvement to overall system's performance (within a given series: results of CS-1.y.1 and CS-1.y.2 runs being very much comparable).**

2.3.3 Large Scale Static Scenarios: Detailed Comparison

The Large Scale Static Scenario has been selected and agreed between EUROCONTROL and VM4C to evaluate the two simulators behaviour when modelling a dense airspace (hundreds of aircraft, tens of ground stations).

Although it involves significant amount of data traffic in both uplink and downlink directions, the scenario has been specified only to provide additional cross-check, and can not be conclusive for the assessment of the VDL4 technology in support for an operational airspace[5], due to its limited modelling:

- static aircraft, i.e. not flying through the modelled airspace;
- no aircraft handovering from ground stations to ground stations;
- no large-scale fading;
- no airborne co-site;

Even if not representative of an operational airspace, the scenario is expected to provide comparable results when run against both VPS and ACTS/VDL4 simulators.

The overall physical and user success rates and on time percentages calculated by VPS and ACTS are within 5% of each other. The VPS results are slightly lower than ACTS which is the opposite of the medium-scale scenario results.

Some similar trends are demonstrated by both ACTS and VPS, for example more collisions on the uplinks compared to the downlinks. However, when looking at the detailed statistics there are some significant differences between VPS and ACTS that need further investigation to explain. For example:

- Higher percentage of physical transmission failures due to collisions in VPS and corresponding lower physical success rate and throughput and lower user success rate and on time percentages.
- Difference in the relative performance of the uplink and downlink.
- Difference in the average round trip and transit delays
- Difference in the offered load.

[5] The Link 2000+ scenario defined in section 4.3 of present document is the key scenario for such exercise.

2.3.4 Conclusions on Simulators cross-check

- Both simplistic and medium scale scenarios have shown the important impact of the simulation duration: a simulated scenario lasting one hour (the VPS limitation) is often insufficient to reach stable results; 10-hours are recommended,
- Both simulators have shown that the 2-steps slot-selection process recommended in a previous simulation campaign (see [6]) provides no significant improvement to the overall system performance. **Such recommendation should be discarded.**
- At low data traffic, both simulators provide similar results. Divergences appear when data traffic increases.

Compared to ACTS, VPS boosts the results of simulations involving mainly short transmission procedures, and decreases those involving mainly long-transmission procedures. This bias seems to be mainly due to VPS' **partial implementation of technical manual's recommendation for DLPDU linkage**. A complete VPS implementation of the DLPDU linkage (or reversely, a modification of ACTS behaviour to reproduce VPS implementation) is expected to provide simulations outputs more comparable under high data traffic.

3. ADVANCED SIMULATIONS

Because cross-check simulations have been run on section 2 on ideal but unrealistic conditions (static aircraft, no-link management thus no GSIF broadcasts, no ADS-B position report broadcasts, simplistic propagation model), this section reruns the medium-scale cross-check scenarios under more realistic conditions, to assess the effect of:

- A more realistic propagation model (involving Large-Scale Fading)
- Mobile aircraft
- Dynamic data-link management (including hand-off management)
- Inclusion of Airborne co-site interferences

To permit valuable conclusions, rerun simulations still only focus on point-to-point communications (i.e. broadcasting of station position through ADS-B reports still being turned off).

All simulations of this section and corresponding subsections have been run under ACTS / VDL4 only (available tool to simulate the above features).

For the 'Advanced Simulations' the VDL4-ACTS has been as validated in-depth through the following steps:

- Comparison with theoretical results (previous sections and C.5)
- The similar results for VPS and ACTS for simple scenarios under low traffic conditions, and the explained differences between VPS and ACTS results in the other medium-scale scenarios[6] used for cross-checks
- The validation achieved and documented in [13] for all additional functions in ACTS (refined propagation model, air traffic movements, airborne co-site interference, etc; those functions are common to VDL2-ACTS and VDL 4-ACTS)

The medium scale scenario has been chosen because it offered a good tradeoff between the required simulation time (a few days) and an acceptable number of ground stations (10) and aircraft (400). The dynamic scenario has been built to be as close as possible to the static configuration: the objective being to have, at any point of time of the dynamic scenario, more or less 400 aircraft active in the simulation.

The results of the two simulations, detailed in Table 6 below, illustrate how aircraft mobility practically degrades the theoretical system's performances. It also showed an interesting side-effect of the difference of airborne and ground station's transmit power: most of the failures due to an insufficient signal strength is experienced in the downlink direction (the aircraft, that receives a ground signal with an acceptable SQP believes its link is operational, while its downlink transmissions can no longer be received by the peer ground radio).

[6] Differences between ACTS and VPS in the Large-Scale Static Scenario require further investigation.

It should be noted that these simulations were carried using the VDL 2 SQP threshold-based algorithm. This is the only specified handover algorithm available at the time of the simulations.[7]

			Unit	ACTS / VDL4 Cross-Check Scenario CS-1.2.3 (medium scale)					
				(simple model)			(more realistic model)		
				U	D	Total	U	D	Total
Physical	Offered Load	(G)	%	11.63	10.58	22.21	11.88	15.16	27.04
			kbits/s	2.23	2.03	4.26	2.28	2.91	5.19
	Throughput	(S)	%	5.04	4.97	10.01	5.00	5.01	10.01
			kbits/s	0.97	0.95	1.92	0.96	0.96	1.92
	Rates	Requests	Nb	26348	24781	51129	27649	42695	70344
		Success	%	90.69	95.92	93.22	89.79	58.85	71.01
		Co-site victim	%	0.00	0.00	0.00	0.78	0.00	0.31
		Collided	%	14.71	4.09	9.57	11.91	6.55	8.65
	Failures	LOS	%	0.00	0.00	0.00	0.22	5.05	3.15
		Power	%	0.00	0.00	0.00	0.00	29.95	18.18
		Co-site	%	0.00	0.00	0.00	0.37	0.00	0.14
		Collision	%	9.31	4.08	6.78	9.63	6.15	7.52
Link	Transit delay	Average	ms	580	230	405	564	158	361
	Round Trip delays	Average	ms	884	488	686	801	475	638
	Handovers (HO)	Total				0			728
User	Requests		Nb	11829	11811	23640	11753	11760	23531
	Effective		Nb	14394	12659	27053	14349	30705	45054
	Success		%	99.83	99.71	99.77	99.27	98.09	98.68
	On-time Transit Dly	(< 5s)	%	97.76	99.45	98.60	97.03	97.90	97.47
	On-time Rnd Trip Dly	(< 8s)	%	98.75	99.50	99.12	97.52	97.92	97.72
	Data rate		%						

Table 6 – Comparison of simulation models (CS-1.3.2)

[7] In 2009 VM4C, LFV and Helios report to be working at the development of alternative Hand-Off algorithm which is based on flight trials and would show significant improvement to VDL Mode 4 performance that met ED120 requirements during flight trials (CPDLC Sweden project; see also 705860_06_03_CPDLC_Sweden_Flight_Trials_report_v02 00.doc).

U: Uplink
D: Downlink

4. POSITIONING VDL MODE 4 POINT-TO-POINT COMMUNICATIONS PERFORMANCE

As VDL Mode 4 is considered as a candidate sub-network to complement, or possibly replace VDL Mode 2 in the future, this section analyses VDL Mode 4 performances through three different set of simulations:

- Comparison of VDL mode 2 and 4 performance based on some of the cross-check scenarios already run on section 2.
- Investigation of VDL mode 4 performance for time-critical applications for which VDL 4 would be solely used.
- Based on a typical Link2000+ scenario (dynamic traffic), analysis of VDL 4 performance in replacement of VDL Mode 2.

4.1 Preliminary VDL Mode 2 and Mode 4 Comparisons based on Simple cross-check scenarios

Three simulators are available to conduct such comparison:

- **VPS (i.e. VDL4)**

  The VDL4 simulator developed by Helios Technology that has been used during initial VDL4 validation campaigns (broadcast and point-to-point).

- **ACTS/VDL4**

  The VDL4 simulator developed by ISA Telecoms that has been used during this study' simulation cross-check exercise (see section 2) and further simulations (sections 3).

- **ACTS/VDL2**

  The VDL2 simulator developed to support VDL2 capacity studies conducted for EUROCONTROL since 2002.

This VDL4 vs. VDL2 preliminary comparison exercise has been made possible thanks to the following considerations:

- As shown in section 2, VPS and ACTS/VDL4 provide convergent outputs when ran on specific crosscheck scenario, with only few diverging – yet well understood and explained – results.
- ACTS/VDL2 is EUROCONTROL's reference for detailed VDL2 simulations. Its model has been thoroughly tested and extensively validated through:

  (a) cross-check campaigns: against two external simulators, including Saltzburg University's VDL 2 simulator based on NAVSIM; a very detailed validation is presented in [13].

  (b) lab tests

(c) live trials : outputs produced by simulations have been checked against live data collected during flight trials: VHF coverage; power consumption budget; SQP measurements.

- ACTS/VDL4 and ACTS/VDL2 shares many features: same input files (aircraft locations and data traffic); same message handling; same statistics computation methods; same VHF propagation models, etc.

This exercise focused on the different saturations in simple scenarios, to identify the maximum VDL Mode 2 and 4 performances in terms of success rate, throughput and transmission delays.

Referring to Table 7, it appears that VDL Mode 2 still performs efficiently when VDL Mode 4 starts experimenting DLE or VSS saturation.

		Transit Delays (i.e. one-way delays)									Round-Trip Delays (i.e. two-way delays)									General Information							
		Average (s)			Std. Dev. (s)			On-time (%)			Average (s)			Std. Dev. (s)			On-time (%)			Throughput (S) kbits/s (%)			Offered Load (G) kbit/s (%)			Success F %	
		VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4	ACTS / VDL2	VPS / VDL4	ACTS / VLD4
CS-0.1.4	DLE saturation (short, downlink)	1.12	256	0.09	1.47	321	0.09	97.20	0.7	99.9	2.61	307.9	0.65	1.65	353.2	0.16	98.74	0.7	99.9		0.13 (0.02)	0.27 (0.08)		0.69 (0.13)	0.54 (0.17)		83.4
CS-0.2.4	DLE saturation (short, uplink)	1.54	236.7	0.10	1.87	302.8	0.11	93.80	0.5	100	3.04	288.5	0.66	1.99	334.6	0.19	97.14	0.8	100		0.21 (0.04)	0.33 (0.1)		0.77 (0.15)	0.6 (0.19)		82.4
CS-0.3.4	DLE saturation (long, uplink)	373	277	0.12	207	363	0.09	0.00	0.3	100	375	347	0.67	207	406	0.17	0.002	0.3	100		1.19 (0.23)	1.06 (0.33)		1.74 (0.33)	1.37 (0.43)		80.3
CS-0.4.4	VSS saturation (short, uplink)	495	10.72	0.13	307	11.5	0.30	0.65	3.7	100	498	12.2	0.88	307	12.9	0.11	0.84	10.2	99.9		2.83 (0.54)	5.62 (1.77)		15.78 (3.03)	10.36 (3.26)		99.62
CS-0.5.4	VSS saturation (short, uplink)	1.02	1.48	0.23	1.66	3.2	0.62	8.05	88.9	99.8	2.51	2.96	0.86	1.78	4.19	1.09	8.23	93.6	100		3.34 (0.64)	6.59 (2.08)		20.85 (4.00)	12.21 (3.85)		99.89
CS-1.3.2	Low traffic load (short, both dir.)	0.67	0.41	0.39	0.88	1.23	1.04	99.20	98.60	98,7	0.94	0.69	1.18	0.93	1.46	1.74	99.74	99.12	99.6		10.01 (1.92)	9.45 (2.98)		22.21 (4.26)	15.46 (4.87)		99.77

Table 7 – Comparison on Cross-Check scenarios

Performance degradations are observed when staturation is experienced in VDL4' DLE or VSS.

4.2 Time-critical applications requirements

The second analysis activity dealt with performances requirements developed for ‘Time-critical point-to-point applications’. Although this concept is rather vague and not unambiguously defined, it generally means applications requesting a better performance level than the one currently specified and deployed for CPDLC-like applications.

4.2.1 Background information

Both CoopATS [19] and MACONDO [18] studies have specified performance for different levels of criticality. The following table summarizes these requirements, that are all expressed as a couple of constrains to be applying to the expected transit (i.e. one-way) delay[8]. If all of these requirements were considered, a very strong impact on communication infrastructure should be expected.

Time Criticality		Message Category	95% Time Delay (sec.)	99,996% Time Delay (sec.)
Critical	**C**	**Critical** **Currently undefined**	**1”**	**3”**
Very High	**V**	**Distress** **indicating grave and imminent danger**	**2”**	**5”**
High	**H**	**Urgent** **having a potential impact on the safety of the aircraft or persons on-board or within sight**	**5’’**	**15’’**
Medium	**M**	**Flight Safety** **Comprising movement and control messages and meteorological or other advice of immediate concern to an aircraft in flight or about to depart, or of immediate concern to units involved in the operational control of an aircraft in flight or about to depart**	**10’’**	**20’’**

[8] Other documents are specifying targeted performance requirements as a combination of a transit (i.e. one-way) delay constraint AND a round-trip (i.e. two-way) delay constraint. For example: 95% of one-way transmissions within 5s and 99.996% of two-way transmissions within 8s.

Time Criticality		Message Category	95% Time Delay (sec.)	99,996% Time Delay (sec.)
Low	**L**	**Routine Surveillance or Navigation**	**30''**	**60''**

Table 8 – High-Level Performances: Maximum Transmission Times (ONE WAY)

The above timing constrains are applicable for end-to-end communications, i.e. from the sender side, up to the receiver side, including the processing time required to propagate the information through the ground infrastructure or display it on a unit (pilot or controller) whenever applicable. As such, they don't exactly correspond to the timing constrains that should normally be applied over the air-ground segment[9]. Yet, these figures represent the least minimum an air-ground technology shall comply to: any technology that is unable to transmit within the indicated constrains would be unsuitable for supporting time-critical ATS communications[10].

In practice, the compliance to the above criteria is a very complex thing to assess, because it depends on too many factors: the total number of aircraft equipped with the technology, the applications involved (AOC & ATC) and their corresponding message rates, the number of aircraft simultaneously flying a given region and the number of ground stations deployed.

4.2.2 Simulation Configuration for identifying an absolute upper bound to throughput per aircraft

The purpose of the conducted simulations is to perform a first positioning of VDL Mode 4 for time-critical applications. The main idea behind the setting of the simulations (station configuration, data traffic, system parameters) is to place the VDL4 system (as well as the VDL2 system) in simple configurations were it can to perform efficiently (no hidden stations, few co-site interferences, ICAO-revisited system parameters[11], messages requiring short procedures only) and then, to vary the message rates determining the limit up to which the High-Level Performance requirements are met.

In doing so, this simulation session provides an upper bound of what the VDL4 system is capable of supporting for a single aircraft, compared to VDL2 placed in similar situations.

[9] The VHF media being the bottleneck of the whole transmission chain, the assumption is that between 60 to 80% of the allowed time shall normally be allocated to VDL transmissions.

[10] On the opposite: a technology fulfilling all the above constraints may possibly not be suitable. This is because the time budget that should normally be taken into account on the air-ground segment is only a portion of the high-level time constraints.

[11] ICAO default system parameters being, as now commonly agreed, ineffective in support to point-to-point communications.

Station Configuration

In order to perform a first positioning of VDL Mode 4 for time-critical applications, the present analysis focused on a simple configuration involving one aircraft and one ground station:

- Aircraft in the En-Route phase
- Distance from ground station: FL250, 50NM
- Average co-site interferences: 53 dB and 1 Mhz separation (135.975MHz).
- Only ATC voice-traffic interfering with VDL Mode 4 traffic reception
- Simulation time: 10 hours (for a sake of stability in the results)

In such configuration:

- the aircraft is in range of the ground station (no losses due to insufficient receive or transmission power),
- collisions are only due to cosite interference.

Data Traffic (rates and length)

For the sake of simplicity, all run scenarios involves the same message rates in the uplink and downlink directions. The message rates vary between 1 to 100 messages per minutes per aircraft.

The user-data lengths have intentionally been set to 32 bytes (fixed length) to exercise VDL4 with **its most optimal transmission protocol for time critical applications** (only short procedures are exercised; long-procedures are not exercised).

System Parameters

For VDL4 scenarios, three parameter sets have been selected:

- The default ICAO parameters (although they are known to be inadequate)
- Parameter set PS2 (see Appendix C.4) and PS4 (see Appendix C.5)

Here again, the PS2 has intentionally been selected to exercise VDL4 with slot selection parameters suited for time critical applications[12] for this type of scenarios.

Based on VDL2-ACTS, similar simulations have been achieved for VDL Mode 2.

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[12] PS2 is, out of the four parameter sets identified for the present study (see C.4), the one that best optimizes transit and round-trip delays – thanks to a narrow slot-selection window.

Msg Rate (msg/min/ac)	Scenario	Targeted transit delay (ONE WAY)			Maximum allowed deviation (ONE WAY)		
		95% in 10s	95% in 5s	95% in 2s	98% in 20s	99.996% in 15s	99.996% in 5s
1	VDL4 default ICAO parameters	OK	OK	OK	OK	OK	NOT FULFIL’ED
	VDL4 parameter set PS4	OK	OK	OK	OK	OK	OK
	VDL4 parameter set PS2	OK	OK	OK	OK	OK	OK
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK
5	VDL4 default ICAO parameters	OK	NOT FULF’ED	NOT FULF’ED	OK	NOT FULFIL’ED	NOT FULFIL’ED
	VDL4 parameter set PS4	OK	OK	OK	OK	OK	OK
	VDL4 parameter set PS2	OK	OK	OK	OK	OK	OK
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK
10	VDL4 default ICAO parameters	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	OK	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS4	OK	NOT FULF’ED	NOT FULF’ED	OK	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS2	OK	OK	OK	OK	OK	OK
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK
20	VDL4 default ICAO parameters	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS4	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS2	OK	OK	OK	OK	OK	OK
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK
30, 40, 50	VDL4 default ICAO parameters	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS4	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS2	OK	OK	OK	OK	OK	NOT FULF’ED
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK
60, 70	VDL4 default ICAO parameters	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS4	NOT FULF’ED	NOT FULF’ED	NOT FULF’ED	NOT F’ED	NOT FULF’ED	NOT FULF’ED
	VDL4 parameter set PS2	OK	OK	NOT FULF’ED	OK	OK	NOT FULF’ED
	VDL2 default ICAO parameters	OK	OK	OK	OK	OK	OK

80	VDL4 default ICAO parameters	NOT FULF'ED	NOT FULF'ED	NOT FULF'ED		NOT F'ED	NOT FULF'ED	NOT FULF'ED
	VDL4 parameter set PS4	NOT FULF'ED	NOT FULF'ED	NOT FULF'ED		NOT F'ED	NOT FULF'ED	NOT FULF'ED
	VDL4 parameter set PS2	OK	NOT FULF'ED	NOT FULF'ED		OK	NOT FULF'ED	NOT FULF'ED
	VDL2 default ICAO parameters	OK	OK	OK		OK	OK	OK
90, 100	VDL4 default ICAO parameters	NOT FULF'ED	NOT FULF'ED	NOT FULF'ED		NOT 'ED	NOT FULF'ED	NOT FULF'ED
	VDL4 parameter set PS4	NOT FULF'ED	NOT FULF'ED	NOT FULF'ED		NOT F'ED	NOT FULF'ED	NOT FULF'ED
	VDL4 parameter set PS2	NOT FULF'ED	NOT FULF'ED	NOT FULF'ED		NOT F'ED	NOT FULF'ED	NOT FULF'ED
	VDL2 default ICAO parameters	OK	OK	OK		OK	OK	OK

Table 9 – VDL 4 /2 results for Time-critical performance requirements for single aircraft on the channel

4.2.3 Synthesis

The analysis of the present simplified scenario (single aircraft operating VDL at various message rates in support to point-to-point communications) shows that:

- When VDL4 is analysed with ICAO standard -default parameters, the support of ATS applications is not meeting time-critical categories (Distress, Urgent, Flight Safety) performance criteria.
- Using modified system parameters PS2[13], the VDL4 technology:
    - Can support Distress communications if the overall message rate remains below 20 msg/min (as a maximum)
    - Can support Urgent communications if the overall message rate remains below 50 msg/min.
    - Can support the Flight Safety communications if the overall message rate remains below 80 msg/min.
    - In the present simplified case, and focusing only on 95%-success figures, the data traffic supported by VDL Mode 4 must remain limited around 50 messages/min to fulfil the "**95% within 2 seconds**" requirement.

In this case with one aircraft and one ground station, it also appears that the point-to-point VDL Mode 4[14] performance is lower than performance achieved by VDL Mode 2.

- In this simplistic case, VDL2 turned out to be fulfilling requirements of communications up to the Distress category. This does not imply that VDL Mode 2 is suitable to support any time-critical applications at large scale.

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[13] As far as this scenario involving co-site interference criterias is concerned, most recent Parameter Set recommended by VM4C during 2007 for use in point-to-point communications (see PS4 specified in Appendix C.5) performs less efficiently than PS2 (specified in Appendix C.4).

[14] One of the design aims of VDL Mode 4 is to maximise the performance of the communication channel when multiple aircraft and ground stations are using the channel.

4.3 Link 2000+ scenario

The third simulation set was based on a typical Link2000+ scenario that has already been used for VDL Mode 2 capacity assessment [16], [17].

In this case also VDL Mode 4 is considered as a replacement of VDL Mode 2.

The characteristics of the scenario are fully detailed in the referenced documents [17-18] [15].

They involve:

- 87 Ground Station deployed over Europe (replication of 2005- deployment made by commercial VDL 2 service providers)
- 1221 aircraft flying the region (this replicates the peak-hour air traffic of the peak 2004 day, in the most congested area of Europe)
- A 1-hour simulation length
- A data-traffic composed of 100% of equipped aircraft supporting AOC traffic and 70% of them also supporting ATS traffic. This to simulate the targeted LINK2000+ deployment around 2014, assuming that AOC migration to VDL has been totally achieved.
- Co-site interferences due to voice ATS: Frequencies (min: 118.00 MHz - max 136.500 MHz); Ant. Coupling: AM/ATC=50dB, AM/OPC=40 dB
- Large Scale Fading (propagation model)
- Handoffs based on SQP with a threshold at 2[16]

The comparison has been made using ACTS/VDL4 v2.1.2 and ACTS/VDL2 v1.96. The VDL 2 simulation is run with VDL 2 standardized default parameters. The VDL4 simulation is run with ICAO revised PS4 parameter set[17] (see Appendix C.5). The detailed results are provided in Table 10 below.

This scenario corresponds to the maximum traffic supported by a single VDL 2 channel in a realistic traffic pattern for Link2000+ deployment. VDL 2 delivers indeed a useful throughput (S) around 13 kbit/s, and an on-time transit delay for about 95% of the transmissions (actually 93.7% reached below 5 sec for one-way; and 96.9 % round-trip reached below 8 sec).

[15] Also available on EUROCONTROL's website, VDL2 section.

[16] Both the VDL 2 simulation and the VDL 4 simulations were carried using the VDL Mode 2 SQP threshold based handover algorithm. This was the only specified handover algorithm available at the time of the simulations.

[17] PS4 is modification of Parameter Set PS0 recommended by former simulation campaign [6] in replacement of currently specified default values [1], and used during Capacity Studies conducted in 2005 and 2006.

4.3.1 Simulation Results

			Unit	ACTS / VDL4			ACTS / VDL2		
				U	D	Total	U	D	Total
Physical	Offered Load	(G)	%	80.28	72.21	152.49	43.39	35.10	78.48
			Kbits/s	15.41	13.86	29.28	13.67	11.06	24.72
	Throughput	(S)	%	19	21.59	40.6	20.10	21.53	41.64
			Kbits/s	3.65	4.15	7.79	6.33	6.78	13.12
	Rates	Requests	Nb	203009	205385	408394	143289	128231	271520
		Success	%	61.44	77.75	69.64	73.9	94.7	83.7
		Co-site victim	%	2.36	0.00	1.17	1.8	00.0	0.9
		Collided	%	54.31	21.7	37.91	30.8	02.5	17.4
	Failures	LOS	%	0.08	2.43	1.26	00.7	00.7	00.7
		Power	%	0.2	4.75	2.49	00.2	02.9	01.5
		Co-site	%	0.48	0.00	0.24	00.1	00.0	00.0
		Collision	%	37.79	14.81	26.24	25.1	01.7	14.0
Link	Transit delay	Average	Ms	2967	3313	3141	1404	210	789
	Round Trip delays	Average	Ms	4219	4283	4251	1834	1483	1652
	Handovers (HO)	Total				4672			2138
User	Requests		Nb	55398	58651	114049	54601	58031	112632
	Success		%	83.71	90.55	87.23	97.7	99.1	98.4
	On-time Transit Dly	(< 5s)	%	79.94	84.91	**82.49**	88.3	98.8	**93.7**
	On-time Rnd Trip Dly	(< 8s)	%	80.98	84.51	**82.8**	95.7	98.1	**96.9**
	Data rate		%				9.29	9.81	9.56

Table 10 Comparison for typical Link2000+ scenario

U: Uplink
D: Downlink

4.3.2 Latest results compared to previous campaign (2005-2006)

Previous capacity assessment campaign had been conducted making use of Parameter Set PS0, i.e. ICAO' default values but specific window selection parameters.

Latest results are based on a thoroughly revised Parameter Set (see PS4 detailed in Appendix C.5). Among other things, this includes:

- Raised maximum number of retransmissions (from 6 to 10), to increase successful transmissions (thus reducing the number of lost transmissions).
- Reduced retransmission delays.
- Reduced window selection depths, to reduce the average time to transmit, over the channel (both random and reserved procedures; cf. V32,V33, V43 through V46).

Collisions

Latest outputs result in an increase of experienced collisions (from 19.57% to 37.09%) mainly due to a deterioration of uplinks (from 30.76% to 54.31%).

This is mainly due to the reduction of windows selection depths[18] that has been changed from 20 to 200, i.e. a 180 slot-depth selection window with PS0, down to a 6 to 75, i.e. a 61 slot-depth selection window with PS4. For each transmitting station, the reduction of the selection window reduces the total number of bursts potentially available (number onto which shall the selection take place), thus increasing the mean number of transmitting stations per available bursts (for random transmissions as well as for reserved transmissions)[19].

Transit and Round Trip delays (Link level)

Average transit delays are not significantly improved (compared to previous campaign), which seems supprising at first glance. Indeed, reducing window's selection depths should normally reduce the transit time. In practice, though, this is partially true: looking in detail at the distribution of transit delays, there is indeed a growing portion of transit delays that performs much more efficiently (i.e. in shorter time). On the other hand, because of the increase of the maximum number of retransmissions[20], there is also a small proportion of transmissions that performs much worse than with previous parameter set. In short, when a transmission succeeds in few attempts, it succeeds faster; but more transmissions require additional attempts – some of them taking long. Average Transit delay value is slightly increased.

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[18] Combined, to a lesser extent, to the increase of maximum number of retransmissions

[19] This is a well known side effect of TDMA-based communications that is equivalent to an increase of persistence.

[20] Perfectly motivated by the desire to reduce total number of lost transmissions.

Average Round-trip delays are improved (i.e. reduced) compared to previous parameter sets.

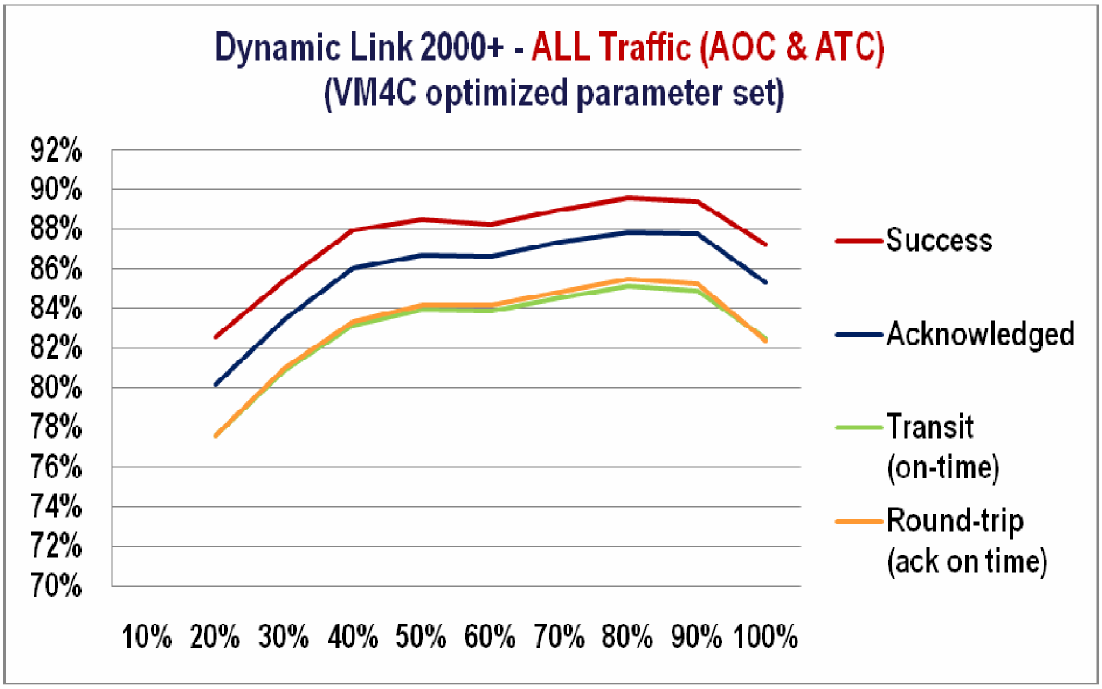
Reminder: Link level transit and round-trip delays do not account for queing delays.

Success, Transit and Round-trip delays (User level)

Outputs from simulations based on PS4 significantly improves overall success rate: from 76% with PS0 to more than 87% with PS4 (and even 91% if looking at ATC transmissions only – see also below). Similar improvements are also observed for global Transit and Round-trip delays..

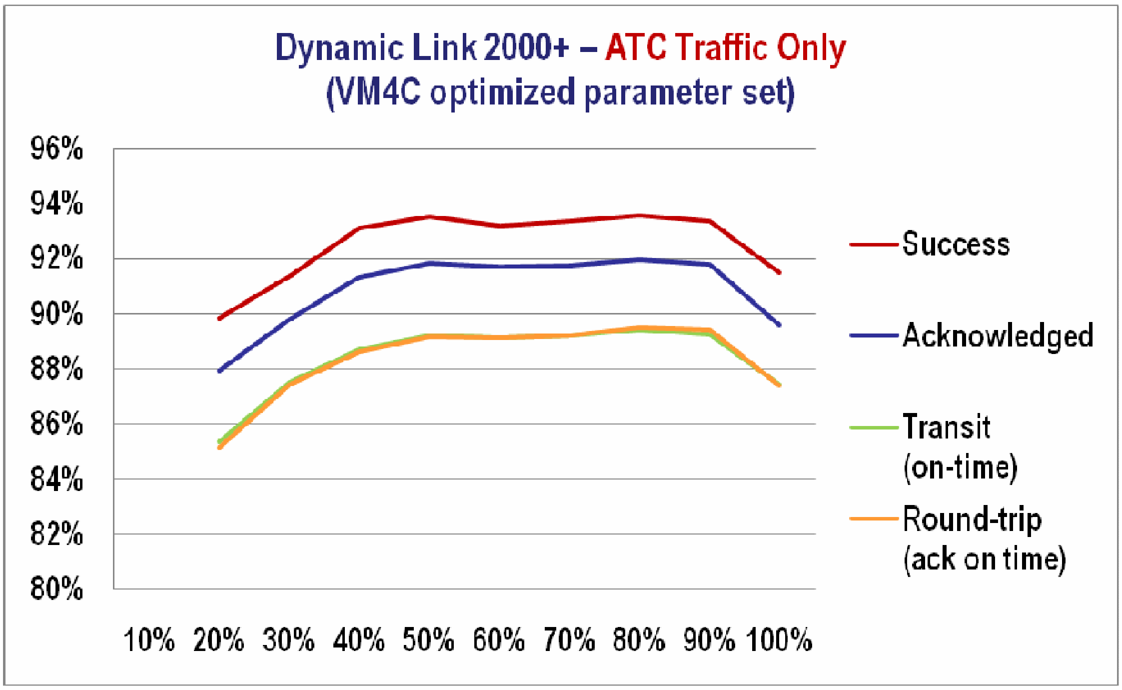
The figures reported in above table accounts for all types of traffic (AOC and ATC). Looking closer at the statistics, a distinction could be made between ATC traffic (the only type of traffic the performance criterions are relevant for) and remaining (i.e. AOC) traffic.

The following two graphs provide the evolution of theses statistics as the simulation progresses (X-axis). The first graph shows statistics evolution[21] for all traffic combines (i.e. figures in above table).



The second graph shows the very same statistics evolution, but this time focussing on ATC traffic only.

[21] NOTE: The decrease at the end of the simulation is normal, and due to an increase of requests in data traffic file (reminder: identical data traffic file has been used for all VDL4 and VDL2 dynamic simulations).



Synthesis

On one side, the reduction of the windows selection depths tends to reduce the mean transmission delays (transit and round-trip). When frames go uncollided over the VDL4 network, they go with parameter set PS4 much quicker than with parameter set PS0.

On the other side, the very same reduction drastically increases the number of collisions, thus the number of retransmissions – and by consequence increases the mean transit time. This increase is only partially compensated by reduced retransmission delays.

With PS4, Success, Transit and Round-trip delays (User level) are significantly improved (compared to PS0 used in 2005 campaign), but below performance criterias applicable for ATC communications.

4.3.3 Additional observations

ATC volumes

The profile (distribution length and sequencing) for ATC data that has been used for VDL4 simulation conducted in 2005 campaing was the same as the one used for the VDL2 run and came from a technical assessment of the traffic generated to the VDL2 subsystem by the protocol entities above the data-link layer.

Such profile includes an overhead due to the [ISO8208 + Mobile SNDCF] that would normally be absent in a [VDL4+FrameMode SNDCF] architecture. That overhead includes:

- a 3-octet long ISO 8208 header;
- few ISO 8208 connection management messages (mainly RR packets: 3 octets long each); and
- an overhead during ISO 8208 connection setup (traffic not significant compared to the two previous items).

Data traffic profile used for 2007-2009 simulations campaign has been adjusted to compensate above overheads and reflect VDL4 used with frame-mode SNDCF (i.e. without ISO8208).

2-steps slot-selection

The 2-steps slot-selection process that proved to be ineffective during cross-check simulations (see 2.3.4) is also ineffective in the typical Link2000+ scenario. The reason is simple and is due to the relatively low effective throughput: at about 1/3rd of total capacity, the slot-selection will always find candidate slots (indeed, a third of slots occupied out of 200-20=180[22] will always leave enough slots left available for selection).

As a matter of fact, on a VDL4 channel dedicated to point-to-point communications, the DLS protocol will always saturate (i.e. the transmit queues will always grow longer and longer) before the 2-step slot-selection process could ever bring any benefit.

[22] With Parameter Set PS0 used during 2005 campaign. The same remark is also valid with Parameter Set PS4 used during 2007-2008 campaign.

5. VDL MODE 4 ENHANCEMENTS

5.1 Introduction

The VDL Mode 4 Technical Manual [1] defines a communication protocol aimed at two complementary purposes: support for broadcast communications and support for point-to-point communications.

As demonstrated during previous and present simulation campaign (see previous sections), the technology, as currently specified in the standard, does not provide the sufficient performance in support to point-to-point communications. The protocol has a number of intrinsic limitations which does not allow for an efficient use of the air-ground bandwidth (ineffective reservation procedures; inefficient segmentation and DLPDU linkage and acknowledgement of messages; etc.).

The configuration parameters identified by previous simulation campaign (see [6]) are not optimal for time critical applications and could not be used to support future data-link traffic. However, the previous simulation campaign also recommended that further investigation into the optimisation of retransmission parameters for specific communication scenarios would be beneficial[23].

That campaign had also considered three potential areas of improvements:

- various set of system parameters (similar to the samples given in Annex C.4, Table 14), including various values for persistence and slot-selection window – the narrower the width of the window selection, the better the performances[24]
- an enhanced slot-selection process which, instead of the specified one-step selection (using DLS parameters only), considers a 2-steps selection process: first using the DLS parameters, and if that step fails to find an available slot, using the VSS ones – a quite narrow DLS window selection combined with a less constraining (i.e. wider) VSS window selection was expected to provide benefits (current study has demonstrated that it won't – see section 2 and conclusions in 2.3.4)
- a co-ordination of ground systems reservation tables to provide an answer to the hidden station effect (see also 5.6.1 below).

Simulation campaign conducted in 2005 showed that none of the enhancements identified above would drastically improve the system's performances, at least up to a stage that could justify VDL Mode 4 deployment in support to crucial or time-critical applications. It had also identified several additional areas where the current standard could be improved, that are further detailed in the following subsections:

- Slot selection process

[23] The new parameter set (PS4) has demonstrated performance benefits, as described in section 5.3.

[24] Actually, the statement is valid only under certain operational conditions – and may no longer remain valid when traffic conditions (number of concurrent users, application profiles, etc.) change.

- Retransmission procedures
- DLPDU linkage
- DLS protocol
- Mitigation of the ‘Hidden Station’ effect
- Link Management

5.2 Slot Selection

The currently defined process for slot selection is based on a random selection of slots available in a given slot window (i.e. between a min and max). The effectiveness of the process is thus directly linked to the width of the given window: the larger the window, the longer the one-way delays. The process being also applied for the acknowledgment slot, the longer the round-trip delays.

One investigation conducted in previous validation campaign (see [6]) consisted in the evaluation of various parameters for the window (V32, V33, V43 thru V46). The study concluded in various system performances but did not attempt to compare the delay values obtained from the simulations to any user level future communication requirements since these were open to debate at the time. Hence it failed to provide precise and exploitable conclusions. There is actually a simple reason hidden behind that. The reduction of the window selection could be suitable (i.e. optimized) under certain traffic conditions (e.g. small message lengths, small message rates), but would proved to be unsuitable at same time under different traffic conditions. There is no such set of parameters that would be suitable for the widest range of operational situations.

Still our analysis has identified that **other slot selection strategies could be envisaged, without drastically redefining the standard**. For example, the window selection could be dropped and replaced by a p-persistent selection on available slots (i.e. not already reserved). Such p-persistent selection process would then statistically give preference to the next coming slots (as opposed to the specified random selection on a given window which gives equal importance to the closest and more distant available slots: respectively the available slot closest to the min window boundary and the available slot closest to the max boundary). The persistence may also take different values based on the priority of the message to be sent (the higher the priority, the higher the persistence). Such p-persistent selection process may even be adaptable to the traffic conditions (the higher the channel load, the lowest the persistence). **This slot-selection strategy would definitely provide better performance results and be suitable to the widest range of operational conditions.**

5.3 Retransmission Procedures

Current specification (see [1], section 1.3.21) documents a random procedure directly copied from the VDL Mode 2 specification.

In VDL2, the retransmission is initiated if no acknowledgement is received after a period of time which depends on the traffic conditions. That period of time the system shall wait for before retransmitting is required because it not possible to know in advance when the acknowledgement is expected. The period of time also includes a random timer to prevent the two stations involved in the collision to retransmit at the same time, thus colliding again.

In VDL4, the time at which an acknowledgement is expected is known in advance, because a slot (the "a_slot") is reserved for it prior to transmission. In current VDL 4 specification [1], a retransmission timer – copied from the VDL 2 standard – is armed as soon as the failure to receive the acknowledgment is experienced (i.e. at the end of the "a_slot"). Such retransmission process, copied from the VDL 2 standard is ineffective for VDL 4:

- There is no need to wait any further once the expected acknowledgement is missing;
- To avoid repeated collisions, there is no need to introduce a random delay before retransmission, because the probability that the two colliding stations have reserved the same acknowledgement slot is already very low.

The retransmission timer that makes sense in VDL2 is irrelevant in a slotted environment: the retransmission process as currently specified introduced a delay that serves no purpose.

Recent 2007-8 simulation campaign has shown that significant performance improvements in point-to-point scenarios can be obtained through optimisation of the VDL4 retransmission parameters. Regarding VDL4 Technical Manual updates, two options are then available:

- Update limited to an update of retransmission parameters (including a proposed value for Q5mult lower than currently defined minimum value)
- Retransmission procedure ([1], section 1.3.21) to be rewritten to remove the unnecessary delay before attempting to transmit again (thus removing references to all Q5 parameters but $Q5_{wait}$: $Q5_{min}$, $Q5_{max}$, $Q5_{mult}$, $Q5_{exp}$; as well as reference the delay involving U(x))

NOTE: this observation is still valid with a revised slot-selection process (5.2 above).

NOTE: this proposal for improvement have been confirmed by 2007-2008 simulation campaign that, through modified retransmission parameters[25], showed the benefit of avoiding unnecessary delay before restarting to transmit.

[25] Cf. Q5max, mult, exp, num and wait as defined per Appendix C.5.

5.4 DLPDU linkage

Current standard recommends the linkage of some DLPDU (see [1], section 1.4.4.12). When implemented, the linkage becomes applicable when, during an ongoing transmission, either the sender or the receiver has additional data to transmit.

One underlying idea of the recommended linkage is to take advantage of the ongoing “protected” (because reserved) thread of communication between the two peers to continue and maintain the (protected) transmission. Without the recommended linkage, the transmission of the additional data requires that, once the ongoing transmission is complete, a new random procedure is initiated (thus “unprotected” because subject to collision).

Another underlying idea of the recommended linkage is to offer an opportunity for high-priority messages to pre-empt an on-going transmission.

Here again, the proposed procedure is suitable for some operational situations, but proved to be inadequate for others. Indeed, when the additional data requires a long transmission, the DLPDU linkage is beneficial, because the procedure’s RTS is sent along with the ongoing transmission ACK. This saves the time of an “unprotected” random procedure for the RTS. But when the additional data requires a short-procedure, the DLPDU linkage has a very undesirable side effect: it slows down the transmission (the random access procedure normally required to send the DATA – that generally takes quite few slots – is replaced by a reservation performed through a slot selection process – that takes much more slots).

The DLPDU linkage recommendations, as currently specified, should just be removed from the standard. DLPDU linkages shall only be kept, and made mandatory, in the sole support of M-link transmissions (transmissions involving a user data that is too long to fit in a non-segmented long-procedure, thus needing segmentation into several M-linked user data packets). These mandatory DLPDU linkages are DATA/RTS and ACK/CTS.

5.5 DLS protocol

Existing DLS specification has proven during previous and current validation campaign to be inefficient.

The main reason is quite simple: frames are acknowledged one at a time. When several transmission requests arrive almost at the same time, they are stuck into transmit queue until all previous frames are transmitted and successfully acknowledged[26]. This limitation is a well-known issue in protocol design (for

[26] For the sake of simplicity, the rational assumes that all frames are of same priority. Indeed, a frame of higher priority will be processed out from a queue before frames of a lower priority, but will still have to wait until the ongoing transmission is acknowledged: frames of lower priority will just be stuck a bit longer in the queue.

additional information, refer to the OSI model and related standards), and has three complementary answers:

- the acknowledgment of groups of data blocks (also known as "**multiple acknowledgements**");
- the **piggy-backing** (the capability to send a data block that also implicitly acknowledges a received data block);
- the **selective reject** of lost frames

Another reason is linked to the fact that VDL4 does not support[27] the **grouping of frames**: each VSS frame has to be transmitted in its own burst; VSS frames to various recipients (point-to-point or broadcast) cannot be concatenated into a larger burst[28].

The surprising thing here is that the initial specification for the VDL4 Data-Link Subsystem was documenting a protocol strongly inspired from VDL2's AVLC which supports both multiple acknowledgements, piggy-backing, selective rejects and frame grouping. Some experts have considered that the complexity of the AVLC protocol, and the corresponding implementation costs, were too high compared to its operational benefits. Mainly for simplicity reasons an alternative protocol has been first considered [14], then submitted to [15], eventually accepted by ICAO and leading to existing standard [1].

This decision to prefer a simplified DLS protocol to the well strained AVLC protocol, turned out to cause important prejudice to the VDL4 efficiency. Indeed, the effect of multiple acknowledgments, for example, can easily be estimated: a protocol supporting this feature can be run twice, once with a flow-control window enabling the feature, another time with a flow-control window of value 1, disabling both the acknowledgement of multiple data blocks and the selective reject features. Simulations run on VDL Mode 2 shown that the overall system performance is between 1.8 to 3.2 times[29] better with than without the multiple acknowledgments feature. And this ratio would get even worth if the piggy-backing could also be turned off (to get closer to VDL4's actual specification). A similar exercise could also be performed to assess the benefits of frame grouping: simulations run on VDL Mode 2 have shown that the overall system performance may be improved by a range from 1 to 1.2 with that feature available (as opposed to a situation where the feature is inhibited).

The analysis identified that for VDL Mode 4 to potentially reach better performance, compatible with ED120 –derived performances (in terms of data-transfer, transit delays and round-trip delays adequate for Link2000+ like

[27] Except the DLPDU linkage, which only support a limited set of frame grouping (here: only at the DLS level). There is no such grouping permitted at the VSS level.

[28] Being the responsibility of the recipients to look into the whole burst for VSS frames, and process only the relevant ones (broadcast or sent explicitly to the station).

[29] The ratio depends on a number of parameters: message rate, supported applications, simulated aircraft. The more loaded the traffic is, the greater the ratio.

scenario), the existing DLS specification should be abandoned and replaced by an AVLC-like protocol that optimizes the use of the VHF link.

5.6 Mitigation of the 'Hidden Station' effect

Two or more ground stations can be distant enough to be out each other ground stations' coverage (a frame sent by one station isn't received by other ground stations), but close enough to have aircraft in common in their respective line-of-sight. Mainly due to the curvature of the earth, reservations made by one ground stations being unseen to other ground stations, undesirable collisions may occur. This phenomenon is known as "the hidden station effect".

5.6.1 Ground-Ground Coordination

One identified workaround, investigated in previous VDL4 simulation campaign (see [6]), consists in sharing all reservation tables between ground stations, thus avoiding these undesirable collisions.

Even if the mechanisms involved for the coordination of ground station's reservation tables lack a detailed documentation[30], the previous simulation campaign showed drastic reduction of collision in uplinks. On some simulated scenarios, the overall system performances were significantly improved.

But because the assessment had been conducted on a limited set of operational traffic conditions, this approach still would require further validation.

Even though, the ground-ground coordination approach is highly debatable, for two main reasons.

The first reason is mainly conceptual. The initial VDL Mode 4 specification relies on the STDMA protocol, which stands for Self-organised TDMA. This protocol derived from the well-known TDMA concept is built upon the idea that each station autonomously organises its reservation table based on the information listen from the channel. In some ways, the proposed ground-ground coordination breaks the underlying rule.

The second reason is more an implementation issue. In practice, it is expected that a widely deployed and operational VDL4 infrastructure would be operated by several service providers: presumably service providers like SITA and ARINC who are already operating VDL2 and other services worldwide; possibly other service providers. The problem comes from the fact that there the benefit of ground-ground synchronisation is depending on the service providers will to accept synchronizing their ground stations reservation table with their competitors'. With the deployment of ground stations that are mainly located where the data traffic is important (i.e. close to airports), there is always (at least) one station from each service provider at

[30] There is no such coordination in the VDL Mode 4 Technical Manual. Report [6] only describes its principles and gives no detailed specification.

each site. As a consequence, the anticipated benefits of the proposed ground-ground coordination would be extremely reduced: two service provider reservation tables being uncoordinated, the number of collisions on uplinks would remain unchanged compared to existing specification.

Because the ground-ground enhancement hasn't been documented in details, it is not clear whether the suggested approach only synchronizes the reservation tables, or if it also coordinates ground stations random accesses. If it only synchronizes the reservation tables, the proposed approach will not prevent from collisions due to random transmissions (who contribute to a very significant part of the total number of collisions experienced).

The main criticisms applying to the ground-ground coordination could be avoided with a different approach presented in next section.

5.6.2 Airborne reservation

The best visibility of the channel being at altitude (the higher the better), one option could be to adopt a dissymmetric reservation procedure, where most (if not all) slot reservations are made by aircraft.

For downlink transmissions, the existing specification would work unchanged. The specification would mainly be modified for ground initiated transmissions to force, whenever required, slot reservations to be made by aircraft.

NOTE: Although this approach is anticipated to improve the overall system performance, it provides no specific answer to collisions due to random channel accesses from two competing ground stations[31]. In any case, the problem always exists in all kinds of competing accesses: air vs. air; air vs. ground and ground vs. ground.

5.7 Link Management

Current VDL Mode 4 Technical Manual specifies Link Management procedures and services (link establishment and handovers) derived from material available in an early version of VDL Mode 2 Technical Manual.

Since then, important evolutions have occurred in VDL 2 as outcome of VDL Mode 2 deployment and experience, reflected for a part in its standards but not reflected in the VDL 4 specification.

- Link management features have been operated and studied for optimisation. Among others studies have been conducted by Eurocontrol on VDL2 Hand – Offs algorithms to investigate various handoff strategies (based on SQP strength, SQP history, SQP threshold, etc.) and have shown significant impact on overall system performance, thus resulting in guidelines for the preferred

[31] And, presumably, neither the Ground-Ground coordination does.

approach[32].

The VDL Mode 4 standard should be developed similarly in Link Management area.

[32] A potential benefit of up to 3% on on-time round-trip delay (the most constraining criteria) having been observed between the most and least efficient handoff strategies. From a system perspective, such potential benefit is very significant.

6. CONCLUSIONS ON VDL 4 CAPACITY ANALYSIS AND DISCUSSION FOR ENHANCEMENTS

6.1 2005 Campaign Conclusions

VDL mode 4 capacity has at this stage been deeply analysed through cross-checked simulations, in some simplified and then some refined scenarios.

All significant differences between simulators outputs or between simulations and theory have been identified and explained, so that there is no doubt remaining in the validity of the developed capacity results.

Those simulations show that the performances and capacity delivered by a VDL Mode 4 sub network are limited. The capacity remains generally lower that the one delivered by existing VDL 2 based infrastructure.

Several parameters optimisations have been analysed, in both previous and present simulation campaigns, but none presents drastic improvement.

Other protocol improvements have been identified and presented that could be further evaluated. They include: a revised slot-selection procedure; an optimized retransmission procedure; the renunciation of most recommended DLPDU linkages; a more efficient DLS protocol alike AVLC; asymmetric air-performed reservations to answer the hidden-station problem.

6.2 Latest Campaign Conclusions

In 2007-2009 timeframe, an update of the study has been achieved with a changed VDL Mode 4 set of parameters (PS4 as specified in Appendix C.5). Then the main simulations results have been updated:

Physical Model

Cross-check exercises of VPS and ACTS simulators have been achieved based on set of key performance indicators.

These exercises have focused on the performance of the VDL 4 physical layer (Appendix I) and on the analysis of simple, medium and then large scale static scenarios. It has been concluded for both that simulators results were sufficiently close to each other at the final stage.

Large Scale Static Cross-Check

Under a work plan agreed during 2007 between EUROCONTROL and VM4C to extend the original cross-check simulations (documented in sections 2.1.1 & 2.1.2), a single large-scale static scenario was defined with a high communication load. The scenario, detailed in Appendix D, uses the revised system parameter Set PS4.

The exercise showed differences between the two simulators (see section 2.3.3). Further investigations are required that, mainly for budget constraints, could not be achieved within this additional campaign.

Capacity

Mainly through the change to a shorter transmission window and with faster retransmissions, the application of the new VDL Mode 4 parameters has delivered a significant improvement in performance.

When operated with the recommended PS4 set of system parameters, analysis have shown the ability of VDL Mode 4 to support, in static situations (representative of the desired LINK2000+ traffic but without repetitions due to fading, hand-off and airborne cosite interference), the “Flight Safety” and “Routine Surveillance or Navigation” criteria.

The analysis of the Link2000+ dynamic scenario with ACTS (here including VDL2 handover algorithm, fading effects, aircraft in movement and airborne co-site interference effect) finally gave an indication of VDL 4 performance – when operated with recommended PS4 parameters set – in an implementation comparable to VDL Mode 2 in Link2000+. As outlined in section 4 the performance meets most but not all the required levels for Link2000+.

The improvement of performance is here also visible but doesn’t reach the required performance levels for Link2000+.

Several areas have been identified in section 5 that could potentially lead to further VDL4 improvements. Among others are:

- **Rewriting the DLS protocol**
- **Optimizing the Link Management performance**
- **Implementing an airborne slot reservation**

Eurocontrol concludes that one or more of the above changes are required to reach performance levels that could justify VDL Mode 4 deployment.

However, the VM4C is currently investigating the potential performance improvement that could be achieved through optimising Link Management. In this respect VDL Mode 4 infrastructure providers have developed and are now testing handover algorithms that are defined to optimise VDL Mode 4 performance. The later remains outside the scope of present document although the latest results are available from VM4C (ICAO ACP WG I/12 WP4;WG-M/16 WP21).

Appendix A. References

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[22] VHF air-ground Digital Link (VDL) Mode 4 radio equipment; Technical characteristics and methods of measurement for aeronautical mobile (airborne) equipment; Part 2: General description and data link layer – ETSI – Ref EN 302 842-2.

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Appendix B. Abbreviations

ac	(or ‘a/c’) Aircraft
ATC	Air Traffic Control
BER	Bit Error Rate
CAP	Controller Access Parameters (Service)
CLNP	Connection-Less Network Protocol
CTS	Clear To Send
DLE	Data-Link Entity
DLIC	Data-Link Initiation Capability
DLS	Data-Link Subsystem
DLPDU	Data-Link PDU
DSB-AM	Double Side Band – Amplitude Modulation
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
ICAO	International Civil Aviation Organisation
LME	Link Management Entity
MER	Message Error Rate
PDU	Protocol Data Unit
QoS	Quality of Service
RTS	Request To Send
SER	Slot Error Rate (VLD4)
STDMA	Self-organised TDMA
TDMA	Time Division Multiple Access
VDL	VHF Data Link
VDL2	VDL Mode 2
VDL4	VDL Mode 4
VDR	VHF Data Radio
VHF	Very High Frequency
VSS	VDL4 Specific Services

Appendix C. Definition of Cross-check Scenarios

Preliminary investigations have identified that a complete (i.e. fully defined) cross-check scenario allowing fruitful exploitation of ACTS and VPS results (both common and diverging results) was involving several levels of characterisation:

- Level 1: Simulator-specific behaviours
- Level 2: Airborne and Ground Station Locations
- Level 3: Data traffic associated with the communicating stations
- Level 4: VDL4 system parameters

The following subsections clarify these levels.

C.1 Simulator-specific behaviours

C.1.1 Ground-Ground Co-ordination

During a previous VPS-simulation campaign, one possible protocol enhancement (not compliant with ICAO VDL4 standard) had been investigated: the sharing of the reservation table between all ground stations of the simulation. This capability, also known as “ground-ground co-ordination”, provides, under certain traffic conditions, valuable improvement of the overall system’s capacity.

This capability is available on VPS only. As a consequence, it shall always be turned OFF in the present cross-check exercise.

C.1.2 Airborne Traffic

Both simulators can be used with a set of aircraft in a static position (simplified air situation for basic simulations).

The initial VPS simulation campaign had no LME and only had been used with very limited dynamic air traffic. At the time of designing cross-check scenarios in summer 2005, main LME functions had recently been added but there was still no experience in running in VPS large scale simulations with fully dynamic traffic, therefore cross-check scenarios are involving - only- static air traffic.

C.1.3 2-steps slot-selection

By design, the performance of VDL Mode 4 point-to-point communication is directly linked to the width of the slot selection window: the larger the window, the longer the delays. At first glance, the answer to VDL4 performance issues seems to be the narrowing of the window selection. But there is a drawback with such an approach: if no slot is available within the selection window (because of a heavy traffic), the ongoing transmission is aborted or delayed depending on the action taken by the VSS[33].

To limit the negative effects identified above, a second protocol enhancement (i.e. non ICAO-compliant) had been investigated during previous VPS-simulation campaign: a second selection process, using a wider selection window, is started in case of failure of the first attempt. Such enhancement is known as the “2-steps slot-selection” process.

ACTS has been modified and adapted to allow simulations with such potential protocol enhancements. This facility can thus be turned ON or OFF on demand on both simulators (an ICAO-compliant implementation assumes a single-step window selection process; i.e. this facility turned OFF). When turned ON, the feature requires duplication of the window-selection-related parameters (i.e. V32, V33, V34 and V35): the primary set is defined at the DLS level, the alternate set within the VSS.

NOTE: The proposed enhancement provides benefits only under lightly loaded traffic conditions. Indeed, as the data traffic grows, the probability for a successful burst-selection within the narrower window selection decreases, up to a channel utilisation threshold beyond which virtually all first attempts fail (the narrower the first window, the sooner the threshold).

C.1.4 Propagation models

ACTS propagation models supports free-space, small-scale and large-scale fading. VPS supports free-space propagation only.

Cross-check simulations shall involve a free-space propagation model.

C.1.5 Multi-priority traffic

To assess the efficiency of the VDL4 protocol with respect to prioritized/non prioritized traffic, ACTS allows dynamic allocation of priorities from a configurable range. ACTS allocates priority according to a Poisson distributions (negative exponential) between 0 (low priority messages) and a configurable maximum (at most 15, the highest allowed priority). For example, with a configured maximum of 2, the tool allocates a priority 0 for most of the messages, a priority 1 for fewer messages, and a priority of 2 for even fewer messages (all following a negative exponential: the higher the priority, the lesser the probability). When the maximum priority is set to 0, all messages are assigned the same priority (i.e. 0).

[33] In both ACTS and VPS, the failure to find a slot in the selection window (or in the first and the second selection window) results in a failure to complete the ongoing transmission. If the failure is during a random transmission request when finding a slot for the response, the VSS resubmits the request for future processing provided the maximum number of retransmission attempts isn’t reached, or cancels the data-packet transmission if reached. Failure to allocate a slot, or group of slots, during an information transfer request or during a response transfer (when a combined frame is used) results in a failure to transmit the burst – thus resulting in a lost frame: it is then the initiator’s role to detect the loss of the expected information transfer or response, and take the proper actions.

In VPS simulations, data traffic is defined through the use of message streams. Message streams are defined based on specified data volumes and transmission rates. The user may combine several message stream definitions to fully characterize the targeted simulated data traffic.

ACTS and VPS features for allocating message priorities are too different to generate comparable prioritized data traffics. Cross-check simulations shall thus involve messages of the same priority.

C.1.6 Link Management

A number of features are related to the management of the links (GSIF emissions and receptions, PECT management, link selection). ACTS, which support dynamic traffic, implements them all.

An LME state machine is implemented in VPS for link initiation in NSCOP mode, and mobile initiated handoff. It performs the main functions of automatic log-on and handover, and termination of retransmission of CTRL packets followed by a later attempt to log-on.

But to obtain comparable results in term of link management procedures, the definition of an aircraft traffic that could exploitable both simulators is a complex and time-consuming activity. In addition, link management procedures are useless with static traffic scenarios (see C.1.2).

Cross-check scenarios shall be run without link-management features (no GSIF transmissions).

C.1.7 Broadcast transmissions

The targeted cross-check simulation campaign focuses on point-to-point communications.

Broadcast transmissions, available in both ACTS and VPS simulators shall be turned OFF (V11 = 0 for all broadcast services).

C.1.8 Simulation duration

Except for specific operational cases (mainly when the technology is unable to sustain the demand) most of the output statistics converge during simulation up to their average “representative” value. The duration of simulation might then be of significant importance when running scenarios (simple and/or complex scenarios).

ATCS has no limitation in terms simulation duration. VPS has a maximum limitation time of 3600 seconds (1 hour).

As a consequence to the above, most of the cross-check scenarios shall be limited to 1 hour simulation time. However in order to get significant statistics the “non” saturated simplistic scenario shall last 10 hours. Averaging shall be made across 10 simulations with VPS. These scenarios are bolded in Table 1.

C.1.9 Linking of DLPDU transmissions

VDL4 Manual [1] section 1.4.4.12 documents a number of possible DLPDU combinations – some of them being mandatory and some of them being just recommended.

Both simulators implements the DLPDU linkages recommended in the manual.

C.1.10 Synthesis

The following table summarises the functional differences between simulators.

Specific Feature	ACTS	VPS	Status for cross-check simulations
Ground-Ground Synchronization	N/A	OK	TURNED OFF
Dynamic Airborne Traffic	OK	N/A	TURNED OFF (static airborne traffic only)
2-steps burst-selection	OK	OK	Tuneable ON/OFF on demand.
Large-scale fading	OK	N/A	TURNED OFF (use free space)
Multi priority messages	OK	N/A	TURNED OFF (unique message priority)
Link Management	OK	N/A	TURNED OFF (V11 set to 0)
Broadcast Transmissions	OK	OK	TURNED OFF (p2p communications only)
Max Simulation time	Any	1h	Simulation time to be limited to 1 hour
Recommended linked DLPDU	OK	OK	Implemented and active in both simulators

Table 11 – Simulator-specific features and tuning for cross-check

From table above, the only feature tuneable on or off on demand on both simulators is the 2-steps burst selection. All other features shall be assigned fixed values (or imply default simulator's behaviour).

C.2 Station Locations (SL)

Airborne stations being static in all cross-check simulations (see C.1.2 above), traffic is only characterised in terms of total number of aircraft distributed across an area covered by a given number of ground stations. The ground stations locations are common to both simulators. Although the method for distributing the aircraft's positions over the area is different between the two simulators, the analysis team having conducted the cross-check have confidence that the differences have no significant impact on the final results.

The following Station Locations (Airborne and associated Ground Station locations) have been identified:

	Station Locations
SL1	1 Ground Station 1 aircraft, 50MN from GS, FL200
SL2	1 Ground Station 100 aircraft, 50MN from GS, FL200
SL3	10 Ground Stations 400 aircraft, 50NM from GS, FL200
SL4	65 Ground Stations 1200 aircraft, 50NM from GS, FL200

Table 12 – Cross-check Station Locations

C.3 Data Traffic (DT)

Data traffic shall be characterized on both transmission ways: uplink (from ground stations to aircraft); downlink (from aircraft to ground stations). Both simulators allow for dissymmetric data traffic characterizations.

Irrespective of the applicable direction, input data traffic[34] is fully characterised through:

- the timing at which packet arrives in the DLS for transmission (message arrival distribution)
- a statistical rule that describes the generated messages' sizes (length distribution)

C.3.1 Message Generation with ACTS

In ACTS, the message arrival distribution always follows a Poisson law (the most adequate law to model telecommunication event of temporal nature: messages entering messages queues, connection setup requests, etc.).

The length distribution may follow either one of the most common statistical laws (Uniform, Gaussian or Poisson are available) or an application-specific distribution. In the later case, a length distribution is characterized through a series of size-ranges associated with a given probability of occurrence (for example: 3,56% of messages having a size between 1 to 5 octets; 7,05% between 6 and 10; etc.; the sum of each probabilities being always equal to 100% - within each range, the length distribution is uniform).

[34] I.e. the data traffic that is provided by the system to the VDL4 sub-system, for transmission. This corresponds to VDL4's user data, out of any VDL4 protocol header and/or protocol-specific messages (such as RTS, CTS or ACK).

C.3.2 Message Generation with VPS

In VPS, the message arrival distribution follows a simulator-specific model. Messages are separated one from each other by a delay that is uniformly picked up between a min and a max value:

E1 $$VPSDelayBetweenUserData = U\left[d_{MIN}, d_{MAX}\right]$$

The length distribution follows a uniform law computed between a min and a max length.

C.3.3 Simulators differences

Length distributions

The difference in the simulator's length distributions is not important, as all cross-check simulation exercises have been run with a user-data of fixed length (configurable by both simulators).

Inter user-data distributions

The only difference then lies in the way the two simulators generate user-data message arrivals. ACTS uses a Poisson law when VPS uses a Uniform law (see equation E1 above). In all cross-check simulations, VPS messages have been generated with a min value of zero (and the max adjusted to match ACTS's Poisson mean value – i.e. twice the value). The following figure illustrates the shape of the two laws when both tuned to obtain an average of 50 (intentionally big, to illustrate the difference).

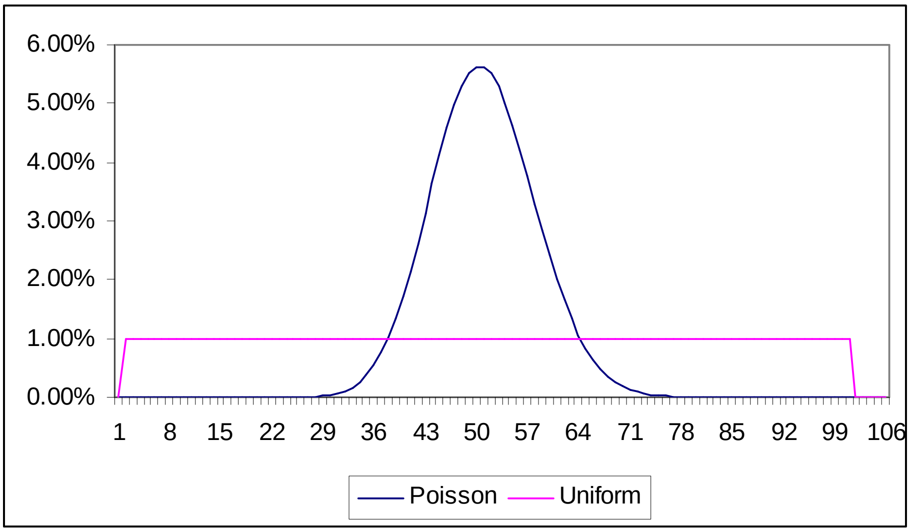

Figure 1 - Uniform[0, d_{MAX} =2* d_{MEAN}] vs. Poisson Probabilities (d_{MEAN} = 50)

With a Poisson law, the frequency of message arrivals is more regular than it is with a Uniform distribution, with rather "slight" oscillations around the targeted mean value. A consequence is that VPS, because it uniformly distributes the delays between the min and the max, allocates much more short (or long) delays than ACTS does – thus creating, more frequently than ACTS does, situations where two messages are queued at the same time and, thus again, **experiencing DLS queuing effect more often** (transient DLS saturations), **or earlier** (permanent DLS saturations), **than it would occur with ACTS**.

These more frequent queuing in VPS only have an impact on overall VDL4 performance when all DLPDU linkage recommendations are always (i.e. with no restriction) activated. Indeed, when no DLPDU linkage is activated, all messages are processed for transmissions the same way (i.e. using a random procedure for the first block or for the RTS). And because VPS only restricts the DLPDU linkage to M-linked transmissions[35], the **simulators' difference in generating the delays between VDL4-user messages has no impact on simulation's outputs** other than slightly higher transmission delays (transit and round-trip) for VPS than for ACTS – for a queued message has to wait until transmission of the previous one before its transmission on the channel can be initiated.

NOTE: With a Poisson law, more than 98% of the probabilities are allocated between ±33.33% around the mean value (see figure below). A more appropriate use of VPS message distribution over time could have been to set d_{MIN} and d_{MAX} to $\frac{2}{3}d_{MEAN}$ and $\frac{4}{3}d_{MEAN}$ respectively.

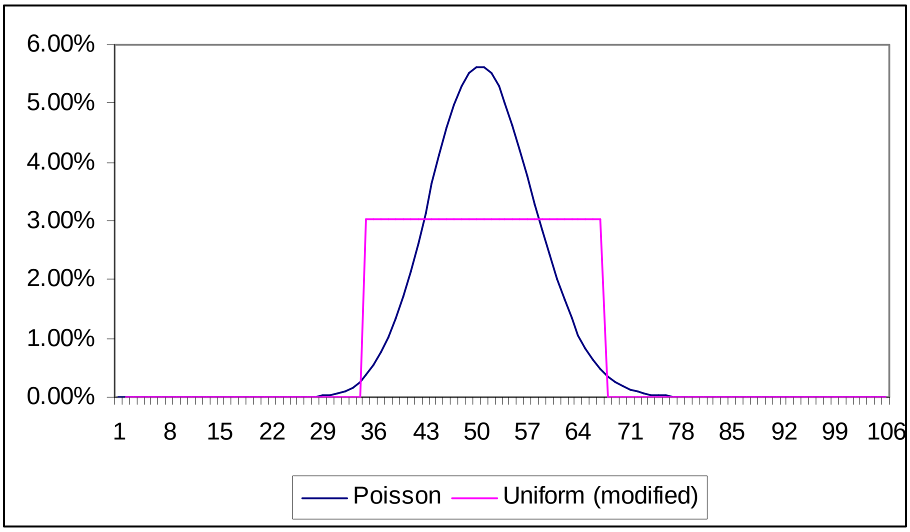

Figure 2 - Uniform[$\frac{2}{3}d_{MEAN}$,$\frac{4}{3}d_{MEAN}$] vs. Poisson Probabilities (d_{MEAN} = 50)

[35] The message lengths used during cross-check is never high enough to involve M-linked transmissions. As a consequence, recommended DLPDU linkage procedures are never exercised with VPS during the cross-check simulation exercise (i.e.: VPS works as if the recommended linkage were not implemented).

Total Number of messages

As explained above, the method of traffic generation in ACTS and VPS differs. Thus it was necessary to ensure that, although not 100% identical, the final product scenarios for the two simulators are equivalent to the extent that any slight differences have minimal impact on the offered load and ensuing channel load.

The team considered that any difference in the total number of messages generated had to be less than 3% to have confidence in the cross-check results.

C.3.4 Selected Data Traffic

The following data traffics (DT) have been identified for cross-check:

Data Traffic profiles	Volumes	Message Rates (msg / min / ac)
DT-us1.1	Uplink only: data = 4 bytes (short procedure, 1-slot) No Downlink	1
DT-us1.2		2
DT-us1.3		3
DT-us1.4		4
DT-us1.5		5
DT-us2.10	Uplink only: data = 10 bytes (short procedure, 2-slots) No Downlink	10
DT-us2.15		15
DT-us2.20		20
DT-us2.25		25
DT-ds1.1	No Uplink Downlink only: data = 4 bytes (short procedure, 1-slot)	1
DT-ds1.2		2
DT-ds1.4		4
DT-ds1.6		6
DT-ds1.10		10
DT-ds1.15		15
DT-ds1.20		20
DT-ds1.25		25
DT-ul4.10	Uplink only: data = 80 bytes (long procedure, 4-slots) No downlink	10
DT-ul4.15		15
DT-ul4.20		20
DT-ul4.25		25
DT-B1	Uplink: data =32 bytes Downlink: data = 32 bytes	Uplink = 0.5 msg / min Downlink = 0.5 msg / min

Data Traffic profiles	Volumes	Message Rates (msg / min / ac)
DT-B2	**Uplink: data = TBC** **Downlink: data = TBC**	**Uplink = 0.5 msg / min** **Downlink = 0.5 msg / min**

Table 13 – Cross-check Data Traffics (DT)

C.4 VDL4 system Parameter Sets (PS0 thru PS3)

Some of the ICAO Doc 9816's default parameter values been inadequate for the support of ATC traffic, an investigation on a subset of them have been initiated. The subset encompasses all parameters having an impact on the system's performance. They are: the persistence involved during random transmission (the probability to be granted on an unused slot) along with windows boundaries involved during slot selection.

The following parameter sets have been considered for cross-check:

	Persistence	DLE windows selection (1st attempt)	VSS window selection parameters (2nd attempt when first fails)
PS0	**0.1**	**V32 = V43 = V45 = 20** **V33 = V44 = V46 = 200**	**V32 = V43 = V45 = 200** **V33 = V44 = V46 = 1000**
PS1	**0.25**	**V32 = V43 = V45 = 20** **V33 = V44 = V46 = 200**	**V32 = V43 = V45 = 200** **V33 = V44 = V46 = 1000**
PS2	**0.1**	**V32 = V43 = V45 = 10** **V33 = V44 = V46 = 25**	**V32 = V43 = V45 = 20** **V33 = V44 = V46 = 200**
PS3	**0.5**	**V32 = V43 = V45 = 10** **V33 = V44 = V46 = 25**	**V32 = V43 = V45 = 20** **V33 = V44 = V46 = 200**

Table 14 Cross-check parameter sets

Parameter Set PS0 being the one recommended by previous simulation campaign [6] in replacement of currently specified default values [1].

Parameter Set PS1 being a variation of PS0, to assess the impact of a greater persistence (giving higher probability of a random access to lead to a transmission on the channel – reducing the time spent on the transmit queues but also increasing the risk of collisions with other stations) on the overall system performance.

Parameter Set PS2 allows the system performance assessment through the reduction of the slot-selection window (only interesting under low traffic conditions).

Parameter Set PS3 being a variation of PS2 exactly the same way PS1 is a variation of PS0 (assessing the impact of a higher persistence).

C.5 Revised VDL4 system Parameter Sets (PS4)

Subsequent to Capacity studies achieved and publicly presented in 2006, recommendations for changes were proposed by VM4C, taking the form of a revised set of system parameters.

This new Parameter Set detailed below (also refered to as “PS4”, as opposed to Parameter Sets 0 through 3 specified in previous sectins, and used during former simulation campaigns), have been used during specific cross-check simulation exercises, or system capacity rerun (see dynamic scenario in section 4.3).

C.5.1 General Block

SARPS_CG1_decay	0.96
SARPS_CG1_inc	1
SARPS_CG1_limit	2000
SARPS_CG1_plea	2
SARPS_CG1_range	100
SARPS_CG1_reach	3
SARPS_L1	3
SARPS_GS1	10
SARPS_GS2	100
SARPS_M1	4500
SARPS_M2inc	2
SARPS_M2limit	160
SARPS_ND1	1511
SARPS_ND2	86
SARPS_ND3	5
SARPS_ND4	271
SARPS_P2	7
SARPS_p	0.25
SARPS_Q1	2
SARPS_Q1_synch	9
SARPS_Q2a	150
SARPS_Q2a_synch	150
SARPS_Q2a_dls	150
SARPS_Q2a_dls_2	150
SARPS_Q2a_dls_3	150
SARPS_Q2a_dls_4	150
SARPS_Q2a_conflict	360
SARPS_Q2b	150
SARPS_Q2b_synch	380
SARPS_Q2b_dls	150
SARPS_Q2b_dls_2	150

SARPS_Q2b_dls_3	150
SARPS_Q2b_dls_4	150
SARPS_Q2b_conflict	360
SARPS_Q2c	0
SARPS_Q2c_synch	0
SARPS_Q2c_dls	0
SARPS_Q2c_dls_2	0
SARPS_Q2c_dls_3	0
SARPS_Q2c_dls_4	0
SARPS_Q2c_conflict	360
SARPS_Q2d	300
SARPS_Q2d_synch	380
SARPS_Q2d_dls	300
SARPS_Q2d_dls_2	300
SARPS_Q2d_dls_3	300
SARPS_Q2d_dls_4	300
SARPS_Q2d_conflict	360
SARPS_Q3	false
SARPS_Q3_synch	false
SARPS_Q3_dls	false
SARPS_Q3_dls_2	false
SARPS_Q3_dls_3	false
SARPS_Q3_dls_4	false
SARPS_Q4	3
SARPS_Q4_synch	3
SARPS_Q4_dls	3
SARPS_Q4_dls_2	3
SARPS_Q4_dls_3	3
SARPS_Q4_dls_4	3
SARPS_Q5min	0
SARPS_Q5max	5
SARPS_Q5mult	0.02

SARPS_Q5exp	1.5
SARPS_Q5num	10
SARPS_Q5wait	60
SARPS_TD1	60
SARPS_TD2	90
SARPS_TL1_initiating	20
SARPS_TL1_responding	60
SARPS_TL2	6
SARPS_TL3	5
SARPS_TL4	20
SARPS_TL5	2
SARPS_TL6	75
SARPS_TM2	1500
SARPS_TV11min	4
SARPS_TV11min_synch	4
SARPS_TV11max	8
SARPS_TV11max_synch	8
SARPS_TV61	4
SARPS_V11	1
SARPS_V11_synch	1
SARPS_V12	0.1
SARPS_V12_synch	0.1
SARPS_V21	1
SARPS_V21_synch	1
SARPS_V22	0.75
SARPS_V22_synch	0.75
SARPS_V32	6
SARPS_V32_2	6
SARPS_V32_3	6
SARPS_V32_4	6
SARPS_V33	75
SARPS_V33_2	75
SARPS_V33_3	75
SARPS_V33_4	75
SARPS_V34	0
SARPS_V34_2	0
SARPS_V34_3	0
SARPS_V34_4	0
SARPS_V35	0
SARPS_V35_2	0
SARPS_V35_3	0
SARPS_V35_4	0
SARPS_V43	6
SARPS_V43_2	6
SARPS_V43_3	6
SARPS_V43_4	6
SARPS_V44	75
SARPS_V44_2	75
SARPS_V44_3	75
SARPS_V44_4	75
SARPS_V45	6
SARPS_V45_2	6
SARPS_V45_3	6
SARPS_V45_4	6
SARPS_V46	75
SARPS_V46_2	75
SARPS_V46_3	75
SARPS_V46_4	75
SARPS_V52	20
SARPS_V61	20
SARPS_V62	3
SARPS_V63	5
SARPS_V64	false
SARPS_V65	10
SARPS_V66	0
SARPS_V67	3
SARPS_VS1	4
SARPS_VS2	12
SARPS_VS3	24
SARPS_VS4	300
SARPS_VS5	10

C.5.2 Physical Parameters

frequency	130
time_delay	180
RFPowerA	-70
A0_Tx_Power_Min	33
A0_Tx_Power_Max	33
A0_Rx_Sens_Min	-96
A0_Rx_Sens_Max	-96
A1_Tx_Power_Min	33
A1_Tx_Power_Max	33
A1_Rx_Sens_Min	-96
A1_Rx_Sens_Max	-96
A2_Tx_Power_Min	38.8
A2_Tx_Power_Max	38.8
A2_Rx_Sens_Min	-96
A2_Rx_Sens_Max	-96
A3_Tx_Power_Min	38.8
A3_Tx_Power_Max	38.8
A3_Rx_Sens_Min	-96
A3_Rx_Sens_Max	-96
V0_Tx_Power_Min	42
V0_Tx_Power_Max	42
V0_Rx_Sens_Min	-100
V0_Rx_Sens_Max	-100
G0_Tx_Power_Min	42
G0_Tx_Power_Max	42
G0_Rx_Sens_Min	-100
G0_Rx_Sens_Max	-100

Appendix D. Large Scale Static Scenario for simulation cross-check

D.1 Introduction

This appendix describes the large scale static cross check scenario used to cross-check the VPS and ACTS simulators under high message load conditions.

D.2 Scenario description

The scenario was defined by Eurocontrol as follows:

D.2.1 Simulator specific behaviour

Static scenario: no aircraft movement, no handover; no airborne co-site interferences; use of a free-space propagation model.

D.2.2 Station locations

87 ground stations and 1170 static aircraft distributed within 600NM of Paris (see Figure 3 - “Distribution of the 1170 aircraft around Paris”)

Ground station locations were taken from WP2 of the VDL Mode 2 Capacity Analysis through Simulations study.

Aircraft positions were created using previous work carried out on future traffic scenarios for the analysis of the predicted 1090ES environment.

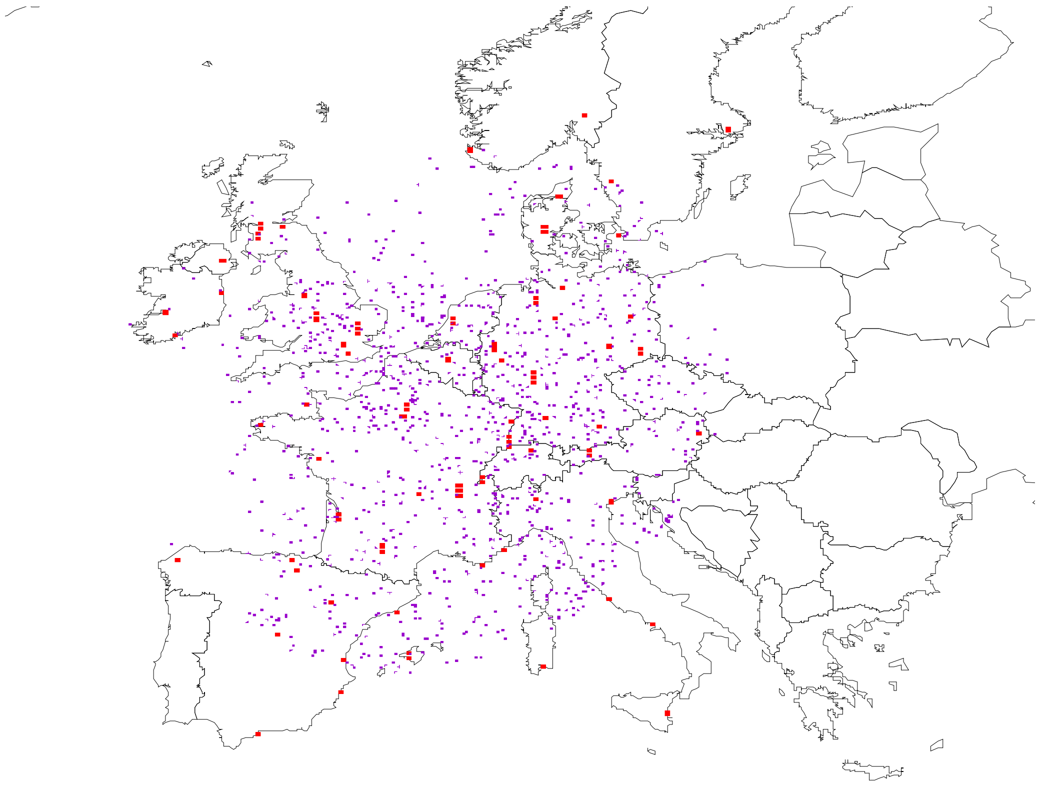

Figure 3 - Distribution of the 1170 aircraft around Paris

D.2.3 Data traffic

A message profile provided by EUROCONTROL and representative of a theoretical LINK2000+ message load (but not covering the significant retranmissions required by fading, hand-off events and cosite interference,, etc (see Figure 4 - “Number of messages transmitted each minute in LSCC scenario” and Figure 5 - “Amount of data transmitted each minute in LSCC scenario”), resulting in a total of 129 430 user-defined messages submitted to VDL4 datalink layer (uplink and downlink).

The message profile provided by EUROCONTROL contained sequences of ATS and AOC message transactions between aircraft and ground stations. However, the profile did not contain any information on the specific identity or locations of the aircraft and ground stations. Therefore, the sequences of message transactions were randomly allocated to aircraft-ground station pairs within the scenario. Aircraft were considered to be connected to their nearest ground station and no handover was simulated.

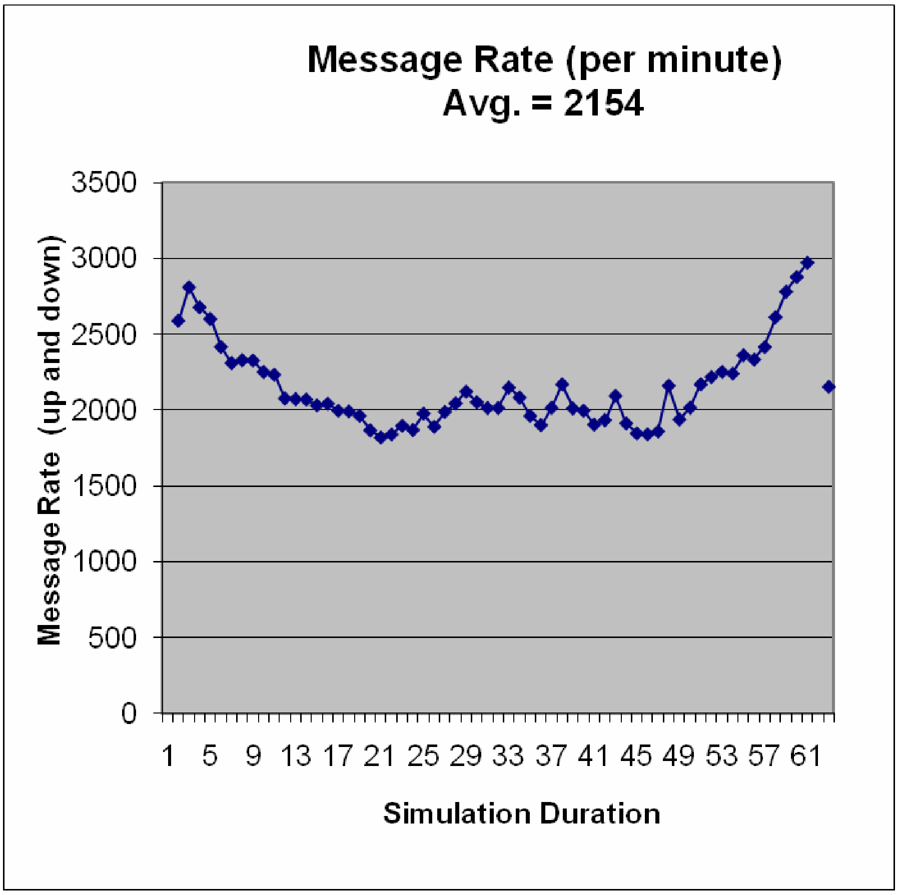

Figure 4 - Number of messages transmitted each minute in LSCC scenario

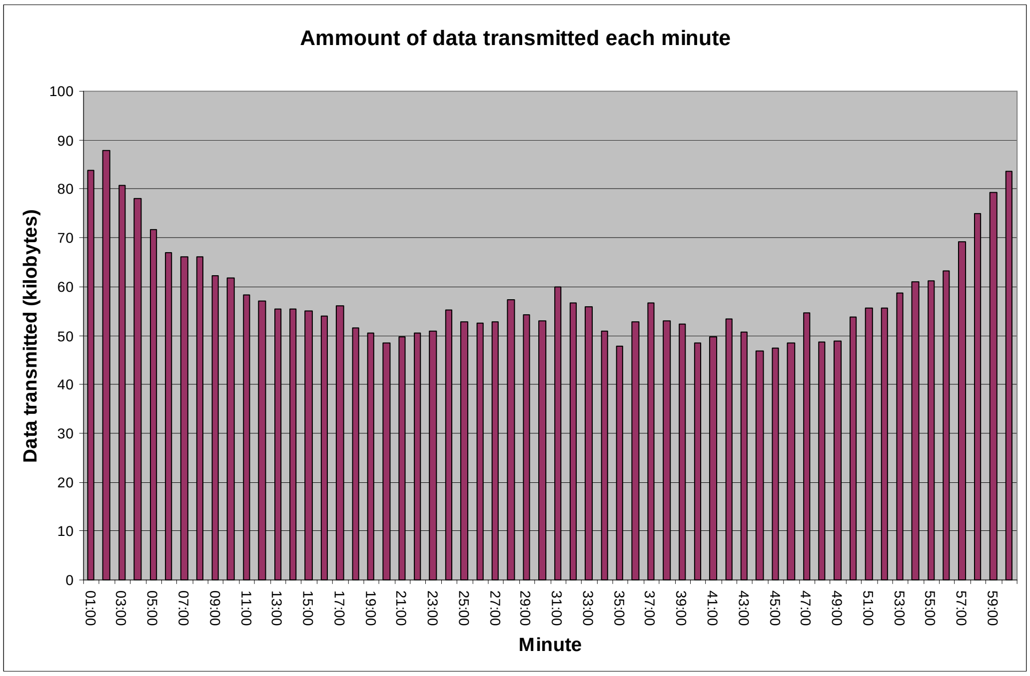

Figure 5 - Amount of data transmitted each minute in LSCC scenario

D.2.4 VDL4 system parameters

Tuned VDL Mode 4 system parameters (PS4) were used (defined in Appendix C.5).

D.2.5 Simulation duration

Scenario is defined for a 60 minutes duration (simulated time), representative of a peak hour.

Appendix E. Theoretical Computation for Simplistic Scenarios

The simplistic scenarios provide simple simulation contexts to which theory can easily be applied. As a consequence, simulation outputs can be compared to the corresponding theoretical expected values – allowing for some straightforward validation of the simulator implementations (ACTS & VPS).

E.1 Background information

E.1.1 Fragmentation

In VDL4, user data sent to DLS for transmission may be subject to segmentation (called “fragmentation” in VDL4’s terminology).

The segmentation is driven by the side of the initial data packet to be sent:

- If the data is small enough to fit, along with the DLS+VSS overheads, into a short procedure, the data isn’t fragmented (the maximum user data length being about 69 bytes);
- Otherwise the data is split into as many fragments as required (of max 135 bytes each)

E.1.2 Flow Control

In VDL4, each DLS fragment[36] that have been sent needs to be acknowledged before the next fragment, from the same initial message or from the next message in the transmit queue, could be transmitted[37]. This statement is equally applicable for both short and long procedures.

E.1.3 (basic) Mean Delays

This section documents the theoretical transit delays and round-trip delays applicable for the transmission of a fragment, considering that the delay of the propagation of the signal between a source and its destination is negligible compared to the other parameters.

Random Access

Under low channel loads, the mean random access time to get access to the channel is mainly driven by the persistence, and is given by the following formula:

[36] The wording “fragment” shall here be considered in the VDL Mode 4 manual’s acceptation: it is either part or whole of a given message. If the message plus any additional (VSS+DLS) protocol overall is small enough to fit into the maximum burst length, the fragment will correspond to the whole initial message. Otherwise, the initial message is split into as many fragments as required.

[37] In the OSI terminology, one would say that the VDL4 protocol has an acknowledgment window of 1.

E2 $$\overline{TD_{rand}} = (\sum_{n=1}^{VS3+1} n.p(n) - \frac{1}{2}) * \frac{60}{M1}$$

Where:

VS3 **Is the maximum number of access attempts**

$p(n)$ **Is the probability to transmit in the n^{th} slot:**

$$p(n) = p \times (1-p)^{n-1} \qquad for \qquad n \in [1; VS3]$$
$$p(VS3+1) = (1-p)^{VS3}$$
$$otherwise \qquad p(n) = 0$$

p **Is the persistence**

Short Procedures

When only small messages are sent – i.e. when applying the short procedure only, and provided the message rates is small, the fragment's mean transit delay is given by given by:

E3 $$\overline{TD_{short}} = \overline{TD_{rand}} + n \times \frac{60}{M1}$$

Where:

n **Is the number of slots required to convey the DATA DLPDU (1, 2 or 3)**

$\frac{60}{M1}$ **Being the duration of a slot (in seconds)**

The fragment's mean round-trip time (the time between the initiation of a fragment transmission and the receipt of the corresponding ACK) corresponds to the mean transit delay + the mean time to get the acknowledgment+ the time to send the acknowledgment itself. It is given by the following formula:

E4 $$\overline{RTD_{shorte}} = \overline{TD_{short}} + \left(\frac{V_{33} + V_{32}}{2} + 1\right) \times \frac{60}{M1}$$

Where:

$\frac{V_{33} + V_{32}}{2}$ **Is the mean number of slots required for the ACK DLPDU (random and uniform selection from the window selection $[V_{32}, V_{33}]$)**

Long Procedures

When larger messages are sent – i.e. when applying the long procedure only – the fragment's mean transit delay corresponds to the mean time to send the RTS + the mean time to get the CTS + the mean time to get the slots for the DATA + the time it takes to send the corresponding burst.

E5
$$\overline{TD_{long}} = \overline{TD_{rand}} + \left(\frac{V_{33} + V_{32}}{2} + \frac{V_{44} + V_{43}}{2} + n \right) \times \frac{60}{M1}$$

Where:

$\overline{TD_{rand}}$	**Is the mean time to send the RTS (random access procedure)**
$\frac{V_{33} + V_{32}}{2}$	**Is the mean number of slots required for the CTS DLPDU (random and uniform selection from the window selection $[V_{32}, V_{33}]$).**
$\frac{V_{44} + V_{43}}{2}$	**It the mean number of slots required for the DATA (information transfer's response), from the slot reserved for the CTS (random and uniform selection from window selection $[V_{43}, V_{44}]$).**
n	**Being the number of slots required to convey the DATA DLPDU (4 or 5).**

Its round trip delay is given by the following formula:

E6
$$\overline{RTD_{long}} = \overline{TD_{long}} + \left(\frac{V_{46} + V_{45}}{2} + 1 \right) \times \frac{60}{M1}$$

Where:

$\frac{V_{46} + V_{45}}{2}$	**Is the mean number of slots required for the ACK (information transfer's acknowledgment), from the slot reserved for the DATA (random and uniform selection from window selection $[V_{45}, V_{46}]$).**

Linked Transmissions

When DLPDU linkage is applicable, and when another fragment is pending in the DLE transmit queue when a fragment is being sent, an RTS for the other (next) fragment is combined with the DATA DLPDU of the fragment being sent (see [1], sections 1.4.4.4.1 & 1.4.4.12). In return, the responding station combines a CTS for the next fragment along with the ACK DLPDU of the fragment being acknowledged.

As a consequence, the random access procedure is never applied, and the RTS/CTS transmission delay for the next fragment is already taken into account in the previous transmission. The mean transit delay for any fragment which RTS/CTS have been combined then becomes:

E7
$$\overline{TD_{lonked}} = \left(\frac{V_{44} + V_{43}}{2} + n \right) \times \frac{60}{M1}$$

And the corresponding mean round-trip delay is given by:

E8
$$\overline{RTD_{lonked}} = \overline{TD_{lonked}} + \left(\frac{V_{46} + V_{45}}{2} + 1 \right) \times \frac{60}{M1}$$

Where:

$\frac{V_{44} + V_{43}}{2}$ **Is the mean number of slots required for the DATA (or DATA/RTS if yet another fragment has to be sent) from the slot reserved for previous ACK/CTS (random and uniform selection from window selection $[V_{43}, V_{44}]$).**

$\frac{V_{46} + V_{45}}{2}$ **Is the mean number of slots required for the ACK (or ACK/CTS) the slot reserved for the DATA (random and uniform selection from window selection $[V_{45}, V_{46}]$).**

n **Being the number of slots required to convey the DATA DLPDU (1, 2, 3, 4 or 5).**

Synthesis

This sub-section documents the values of the three cases above for the simplistic cross-check scenarios (i.e. when parameter set PS0 is applicable).

Under low traffic conditions, the mean random access time varies from 120 (channel load = 0%) to 150 ms (channel load = 20%): $\overline{TD_{rand}} \approx$ 130 ms.

For following table summarises provides basic fragment transmissions for cross-check scenario CS-0.x.x:

	Mean Fragment's Transit delays (s)	Mean Fragment's Round Trip delays (s)
1-slot short procedure	0.14	1.61
2-slots short procedure	0.16	1.63
4-slots long procedure	3.12	4.60
1-slot linked procedure	1.48	2.98

	Mean Fragment's Transit delays (s)	Mean Fragment's Round Trip delays (s)
2-slot linked procedure	1.49	2.99
4-slots linked procedure	1.52	2.32

Table 15 Basic Mean Round Trip Delays for Fragments

IMPORTANT NOTE: the above basic delays are applicable for fragments only and do not take into account delays on transmit queues (VSS and DLE). As such, they provide just an indication (a lower bound) of what simulation delays could be.

E.1.4 Saturations

In VDL4, three saturations may be potentially experienced individually. Under certain traffic conditions, then may be experienced concurrently.

Channel Saturation

The first saturation is linked to the VHF media itself and is dependent on the overall data traffic (the channel load): the denser the traffic, the more difficult it is for new comers to get access to it. In practice, though, such saturation, which affects all communicating entities, is seldom met (the other saturations will occur before).

The other saturations are linked to VDL4 design itself, and have nothing to do with the channel load. The first one occurs at the DLE level, the other at the VSS level.

DLE saturation

This saturation is due to the conjunction of both:

- the fact that a DLE maintains a queue for all pending (or ongoing) transmissions (see [1], sections 1.4.4.3.1.1); and
- the flow control mechanism applicable (see E.1.2), which causes pending fragments, if any, to be retained at the DLE level until the acknowledgment of the previous fragment is received.

The effect shows up more or less rapidly, depending on the applicable transmission procedures (quicker when a majority of long procedures have to be applied).

In addition, the effect is even further increased by the application of linked DLPDU, which causes any transmissions (short or long) to be treated as if falling into the long procedure category.

VSS saturation

This saturation is due to the conjunction of both:

- the fact that the VSS implements a single queue – also called the “random access queue” – for the random transmissions of all supported DLE (see [1], section 1.3.7.2.4); and
- a random transmission shall be completed (or aborted) before any other pending random transmission request can be served (see [1], section 1.3.7.1)

This effect never shows up on airborne sides, where the VSS supports one DLE only during most of the time (and 2 DLEs during handoffs).

The VSS saturation shows up on ground stations only, when all supported DLE tries to concurrently initiate random transmissions. In other terms, it shows up when both below conditions are satisfied:

- the VSS supports a large number of aircraft (about 100 or more)
- The messages rates for each DLE are small enough so as to avoid DLE saturation situations. Indeed, when a DLE saturation occurs, the transmissions no longer goes through random procedures – thus limiting the risk to experience VSS saturation.

E.2 Cross-Check Scenarios CS-0.1.x

The CS-0.1 series involve a 1-slot burst transmission through the DLS, from air to ground, on a unique air-ground communication link, at various messages rates: 10, 15, 20 and 25 messages per minutes.

The aircraft is intentionally kept close to the ground station, so that no loss could be experienced due to the signal’s strength or the line-of-sight. The link being unique and the communication being unidirectional, no burst collisions are to be expected.

The purpose of the series is to experience saturation of the DLE transmit queue.

E.2.1 Maximum message rate before DLE saturation

At first glance, it seems that the DLE saturation will be experienced when the rate at which messages arrive at the DLE is higher than the rate at which the DLE can serve the pending messages. According to Table 15, the DLE seems to be able to serve up to about 60 / 1.61 ≈ 37 messages per minute (1-slot short procedures).

The above maximum message rates would be accurate if messages were sent to DLE for transmission at periodic intervals. In practice, though, messages are generated via distributions that more adequately reflects real mode of operation: two generated messages might be quite close in time (it is only the mean time between two consecutive messages that guaranties a constant overall message rate).

Due to the linking of DLPDU, a 1-slot transmission that would normally be sent through random procedure (fragment’s mean round-trip delay of 1.61s) will be sent via an information transfer (fragment’s mean round-trip delay of 2.98 s) if two new messages arrive at the DLE before an ongoing transmission is complete, i.e. if two new messages arrive at the DLE within 1.61 s while the DLE is currently transmitting. Such saturation of the DLE may be transient, since two other generated messages (later in the simulation) may be separated by more than 2.98 s, allowing the DLE to switch from a linked-transmission mode back to the normal random transmission mode.

A permanent DLE saturation situation will only be experienced when, once “hooked” to a linked-transmission mode, the DLE is unable to switch back to the random transmission mode. In other terms, a (permanent) DLE saturation will actually be experienced when the rate at which messages arrive at the DLE is about the maximum rate at which linked DLPDU transmissions can be served, i.e. about 60 / 2.98 **≈ 20 messages per minute**.

E.2.2 Transit and Round-Trip delays

Because transient DLE saturation situation might be experienced quite easily (see E.2.1 above), the mean transit delay (respectively the mean round-trip delay) is expected to be a mix of E3 and E7 (respectively E4 and E8) – depending on the proportion of transmission falling into the random transmission or in the linked-transmission category – thus (see Table 15) always higher than 0.14 s (respectively, higher than 1.61 s).

When experienced, a permanent DLE saturation will cause messages to be stuck into the DLE transmit queue, thus causing the transit delays and round-trip delays to increase progressively as the simulation runs (the longer the simulation, the longer a message waits in the transmit queue, the higher the delays).

E.2.3 Success rates

Before saturation is experienced, the overall success rate, for which no time constraint apply, is expected to be very good (close to 100%).

When saturation is experienced the success only depends on the rate at which messages arrive at the DLE, compared to the maximum rate the DLE can serve. The rate is also constant (as opposed to Transit and Round-Trip delays that are non-stable): the proportion of messages being successfully sent (corresponding to the maximum message rate before DLE saturation) compared to the number of generated messages is an invariant.

At 25 messages per minutes, **the success rate is** about 20/25 = **80%**.

E.3 Cross-Check Scenarios CS-0.2.x

The CS-0.2 series involve a 2-slot burst transmission through the DLS, from ground to air, on a unique air-ground communication link, at various messages rates: 10, 15, 20 and 25 messages per minutes.

The purpose of the series is to check that the simulator’s behaviour is very similar to the CS-0.1 series (one being the symmetrical case of the other – all other things being equal). Expected results shall be comparable.

E.4 Cross-Check Scenarios CS-0.3.x

The CS-0.3 series involve a 4-slots burst transmission through the DLS, from ground to air, on a unique air-ground communication link, at various messages rates: 10, 15, 20 and 25 messages per minutes.

The purpose of the series is to experience saturation of the DLE transmit queue, which shall, because of the length of the data to be sent that requires long procedures, be experienced much faster (i.e. at smaller message rates) than with the CS-0.1 and CS-0.2 series (that involve short-transmission procedures only).

E.4.1 Maximum message rate before DLE saturation

Following the same rational as documented for CS-0.1 and CS-0.2 series, the saturation is given by the saturation due to linking of DLPDU (same as CS-0.1 and CS-0.2: about **20 messages per minutes**).

When, in the CS-0.1 and CS-0.2 series the simulation start with short transmission for the beginning of the simulation and gets hooked to linked-transmissions, the CS-0.3 series (because the basic delays are much higher with long procedures) indeed starts with long-transmissions, but gets hooked to linked-transmissions much faster: almost immediately. In other terms, at a message rate close to the saturation point, the CS-0.3 will converge much quicker to a permanent linked-transmission situation.

E.4.2 Transit and Round-Trip delays

Because transient DLE saturation situation might be experienced quite easily (see E.2.1 above), the mean transit delay (respectively the mean round-trip delay) is expected to be a mix of E5 and E7 (respectively E6 and E8) – depending on the proportion of transmission falling into the pure long-transmission or in the linked-transmission category – thus (see Table 15) always higher than 1.52 s (respectively, higher than 2.32 s).

When experienced, a permanent DLE saturation will cause messages to be stuck into the DLE transmit queue, thus causing the transit delays and round-trip delays to increase progressively as the simulation runs (the longer the simulation, the longer a message waits in the transmit queue, the higher the delays).

Because the convergence to a linked-transmission mode is performed quicker than for the CS-0.1 series, mean transit and round-trip delays are expected to also increase faster (as the message rate increases – compared to the CS-0.1 series).

E.4.3 Success rates

Following the same rational as for the CS-0.1 series:

- Before saturation is experienced, the overall success rate is expected to be very good (close to 100%).
- When saturation is experienced the success only depends on the rate at

which the messages arrive at the DLE. At 25 messages per minutes, **the success rate is** about 20/25 = **80%**.

E.5 Cross-Check Scenarios CS-0.4.x

The CS-0.4 series involve a 1-slot burst transmission through the DLS, from ground to air, on an important set of concurrent communication links (100 aircraft served), at various messages rates: 1, 3, 4 and 5 messages per minutes.

The purpose of the series is to experience saturation of the VSS random access queue.

E.5.1 Collisions?

Because communication is uplink only, the ground VSS normally has total control over the reservations to be made for aircraft responses.

But, as this has been shown in E.2.1, and because message generation is random, linked-transmissions (due to transient or permanent DLE saturation) may show up even with low message rates. When occurring, linked-transmissions have a side effect on allocations: reservations that would normally be performed by one side (in the CS-0.4 series: by the ground side) are then performed by the other side (here: the airborne DLE).

Because all stations are in each other's line of sight **no collisions shall be experienced**, even if two linked-transmissions occur concurrently on two air-ground links (the reservation for the CTS being made by the ground VSS, the airborne DLE will never have to respond at the same time: the information transfer to be made by the first aircraft to respond, and consequently the slots reserved for the response/DATA and the associated acknowledgment, will be known by the second aircraft).

E.5.2 Maximum message rate before VSS saturation

The VSS saturation will be experienced when the VSS has too much random request to satisfy, and cannot process them all in a timely manner.

Having a mean time to perform a random transmission $\overline{TD_{rand}}$ of 120 ms, **the maximum number of random transmissions a VSS is able to serve** under low traffic condition is 60 / 0.12 = 500 random requests per minute for all supported DLEs, i.e. **5 messages / minute / aircraft**.

E.5.3 Transit and Round-Trip delays

Before VSS saturation is experienced, the transit and round-trip delays are expected to be rather close to the theoretical values (respectively 0.14s and 1.61s at low message rates) and **both on-time transmission and round-trip rates should stay quite flat around 100%.**

When VSS saturation is experienced, the corresponding delays induce another side effect: the supported DLEs, which round-trip delays increase, also experience saturation – thus increasing even further the overall experienced delays. At VSS saturation, **both on-time transmission and round-trip rates are expected to decrease sharply** (cumulated effects of VSS and DLE saturations).

E.5.4 Success rates

Before saturation is experienced, the overall success rate, for which no time constraint apply, is expected to be very good (close to 100%).

Even after VSS saturation, there is still some margin left for success rate: it will only decrease when the induced delays are so high that all DLEs experience permanent saturation. None of the messages rates identified for the CS-0.4 series is high enough to induce such situation.

For all message rates, the success rate is expected to be close to 100%.

E.6 Cross-Check Scenarios CS-0.5.x

The CS-0.5 series involve a 1-slot burst transmission through the DLS, from air to ground, on an important set of concurrent communication links (100 aircraft served), at various messages rates: 1, 2, 4 and 6 messages per minutes.

The purpose of the series is to experience collisions.

E.6.1 VSS saturation?

Because most of the allocations are performed by aircraft, VSS saturation is not expected (on aircraft, the VSS only serves one DLE).

The only allocations that are not performed by aircraft, are the one due to linked-transmissions. Although it is true that transient DLE saturations are expected, the experienced message rates are too low to cause permanent DLE saturation on all supported aircraft, at the same time.

As a consequence, no VSS saturation is expected at all.

E.6.2 Transit and Round-Trip delays

Due to collisions, that should be observed even at low message rates, transit and round-trip delays are expected to be significantly higher than the corresponding theoretical values (respectively 0.14 and 1.61s as given by Table 15).

When collisions are experienced, the loss is only detected upon non-receipt of the expected response. A timer is then armed before retransmission is attempted (see [1], section 1.3.21.2). The induced delays are then higher than the ones experienced with VSS situations, but not high enough to induce permanent DLE saturation.

The higher the message rate, the higher the probability to experience collisions, and the higher the induced delays.

E.6.3 Success rates

Collisions have effects on both transmission and round-trip delays, but are not high enough to affect the overall success rate.

For all message rates, the success rate is expected to be close to 100%.

Appendix F. Simulators Output Definitions (Performance Indicators)

This appendix provides definitions for statistics that are common to both simulators (harmonized definitions).

Definitions	
Physical	
Channel Load (U)	**Number of occupied slots during the past minute (valid on a per-station basis only – not significant at system level).**
Offered Load (G) (kpbs)	**Number of bits transmitted over the channel, including overheads and retransmissions, independent of success or failure to receive – per second.**
Throughput (S) % (kpbs)	**Number of bits transmitted and correctly received (by its destination for point-to-point frames – or by any receiver in case of broadcast frames), including retransmissions – per second.**
Transit Delays	
One-way delay	**Delay between a user data is submitted to a VDL4 layer for transmission on one side, and its successful receipt by the peer VDL4 layer and delivery to the peer user on the remote side. The delay takes into account any time spent in the transmit queues (DLS and/or VSS) and any retransmission (if needed). When the user data is too large to be sent via a short procedure, the delay includes the RTS/CTS exchange. When a user data requires segmentation (M-linked transmissions), the delay terminates when the last segment (M-bit set to zero) is successfully received (i.e. all segments in sequence and without errors).**
One-way on-time (%)	**Percentage of one-way delays that are below a given performance criteria (configurable parameter). During this study's simulations, this one-way upper bound was set to 5 seconds.**
Round-trip Delays	
Two-way delay	**Delay between a user data is submitted to a VDL4 layer for transmission and the receipt, from the peer VDL4 layer, of the corresponding acknowledgment. It corresponds to the one-way delay plus the time it takes for the ACK for the last segment to be sent back to the sender (including retransmissions, if the returned ACK is lost on its way back to the sender).**
Two-way on-time (%)	**Percentage of two-way delays that are below a given performance criteria (configurable parameter). During this study's simulations, this two-way upper bound was set to 8 seconds.**

Appendix G. ACTS Standard Implementation Conformance

This appendix documents the ACTS/VDL4 compliance with applicable standards.

Unless explicitly specified for the purpose of a given simulation exercise, all ACTS/VDL4 system parameters are assigned the default's standard values. By documenting the ACTS/VDL4 compliance with the applicable standards, this appendix also provides a reminder of the default values applicable during simulations.

Because functional requirements in the ETSI documents (ref [20] to [23]) are cut and paste from the ICAO Technical Manual (see [1]), the later prevails over the other ones, and is always referenced first. In other terms, whenever a discrepancy exists between the ICAO document and any ETSI reference, the requirement as specified in the ICAO document prevails. ETSI references are given for information only.

The last two columns of each requirement provides indication of the support (a "Y" for "Yes") or non-support (a "N" for "No") in, respectively, the ground (column "Gnd") and airborne (column "Air") implementation of VDL4 within ACTS. "N/A" (for "Not Applicable") indicates a requirement that is, per the standard, not applicable for the corresponding implementation (airborne or ground side).

G.1 MAC sublayer

G.1.1 Services

Requirement reference		Gnd	Air
[1].1.2 [20].5.1.1.1 [22].5.1.1.1	The MAC sublayer shall acquire the shared communication path so as to provide the services defined in [1].1.2.1.	Y	Y
NOTE: The functions performed by the MAC sub-layer should be "transparent" to higher functional layers.			

G.1.2 MAC sublayer services

Requirement reference		Gnd	Air
[1].1.2.1.2 [20].5.1.2.1 [22].5.1.2.1	The MAC sublayer shall accept from the physical layer a continuous indication of channel idle/busy status and signal level (see [1].1.2.4).	Y	Y
[1].1.2.1.2 [20].5.1.2.2 [22].5.1.2.2	The MAC sublayer shall accept from the VSS sublayer a burst for transmission, accompanied by the time to transmit it.	Y	Y
[1].1.2.1.2 [20].5.1.2.3 [22].5.1.2.3	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.	Y	Y

G.1.3 MAC sublayer parameters

General

Requirement reference		Gnd	Air
[1].1.2.2 [20].5.1.3.1.1 [22].5.1.3.1.1	MAC service system parameters shall be as described in [1].Table II-1-3.	Y	Y

[1].Table II-1-3: MAC service system parameters

Symbol	Parameter Name	Minimum	Maximum	Default	Increment
M1	Number of slots per superframe	n/a	n/a	4 500 slots	n/a
M2_inc	Filter increment for receiver blocking check	1 slot	256 slots	2 slots	1 slot
M2_limit	Filter threshold for receiver blocking check (network entry)	1 slot	65 536 slots	160 slots	1 slot

Parameter M1 (number of slots per superframe)

Requirement reference		Gnd	Air
[1].1.2.2.1 [20].5.1.3.2.1 [20].5.1.3.2.2 [22].5.1.3.2.1 [22].5.1.3.2.2	The parameter M1 shall be the number of available slots per superframe. A superframe spans a period of 60 s	Y	Y
NOTE: M1/60 slot spans a time interval of one second. The M1 increment forces M1/60 to be an integer. This simplifies the protocol since a slot counter (or equivalent) can be started at the boundary between any two consecutive UTC seconds.			

Parameter M2_inc and M2_limit (MAC layer control parameters for network entry)

Requirement reference		Gnd	Air
[1].1.2.2.2.1 [22].5.1.3.3.1	An m2 filter shall be maintained by a station for each active channel as a measure of the uncertainty of the reservation data.	Y	Y
[1].1.2.2.2.1 [22].5.1.3.3.2	Each m2 filter is controlled by parameters M2_inc and M2_limit, which, in turn, define the parameters of the following algorithm in which m2 is updated after every slot: m2k+1 = m2k + M2_inc — if receiver function “on the channel” is blocked by the transmission of the same station on the same channel (e.g. through a common antenna) m2k+1 = max[(m2k − 1), 0] — if receiver function is not blocked	Y	Y
[1].1.2.2.2.2 [22].5.1.3.3.3	If m2 ≥ M2_limit, m2 shall be reset to zero (m2 = 0) and the station shall execute a network entry procedure.	Y	Y

G.1.4 Time synchronization

Within a simulation, all airborne and ground stations are sharing the same time reference, given by the computer's internal clock onto which the simulation is running. As a consequence, all stations of a simulation are assumed to run with a highly reliable primary time source.

Primary synchronization mode

Requirement reference		Gnd	Air
[1].1.2.3.1 [20].5.1.4.1.1 [22].5.1.4.1.1	Under normal operating conditions, a station shall maintain time synchronization such that the start of each successive group of M1/60 slots is synchronized with the start of any Universal Time Coordinated (UTC) second to within a two-sigma value of 400 ns.	Y	Y

Secondary synchronization mode[38]

<table>
<tr><th>Requirement reference</th><th></th><th>Gnd</th><th>Air</th></tr>
<tr><td>[1].1.2.3.2
[20].5.1.4.2.1
[22].5.1.4.2.1</td><td>A station shall be capable of maintaining time synchronization such that the start of each successive group of M1/60 slots is synchronized with the start of any UTC second to within a two-sigma value of 15 µs.</td><td>N</td><td>N</td></tr>
<tr><td colspan="4">NOTE 1: One method of obtaining secondary synchronization mode is to synchronize to the slot boundaries that are defined by a station declaring primary time.
NOTE 2: Secondary time is used only when the primary source has failed. A station using secondary time shall however revert to primary time whenever primary time is available.
NOTE 3: Secondary time is regarded as failure mode.</td></tr>
</table>

Alignment to UTC second[39]

Requirement reference		Gnd	Air
[1].1.2.3.3 [20].5.1.4.3.1 [22].5.1.4.3.1	For stations maintaining primary or secondary time, the start of each successive group of M1/60 slots shall be aligned with a UTC second.	N	N

[38] Support of the primary synchronization source only is assumed for all stations.

[39] Simulations need no alignment to UTC time.

Data quality level[40]

Requirement reference		Gnd	Air
[1].1.2.3.5.1 [20].5.1.4.4.1 [22].5.1.4.4.1	The certified quality level shall indicate that timing and position information provided by the station can be used by other stations as a means of deriving position information.	N	N
[1].1.2.3.5.2 [22].5.1.4.4.1a	When a station is deriving position information from the transmissions of other stations, it shall only use data from stations that have declared the certified data quality level.	N	N
[1].1.2.3.5.3 [20].5.1.4.4.2 [22].5.1.4.4.2	There is no need to indicate the certified data quality for secondary and tertiary timing level.	N	N
NOTE: The certification of stations for use as “pseudolites” in order to support secondary navigation will be under the control of an authority, such as the civil aviation administration.			

G.1.5 Slot idle/busy notification

Slot idle detection

Requirement reference		Gnd	Air
[1].1.2.4.1 [20].5.1.5.1.1 [22].5.1.5.1.1	A station shall consider the slot idle if the channel idle/busy status supplied by the physical layer is idle at the start of the slot.	Y	Y

Slot busy detection

Requirement reference		Gnd	Air
[1].1.2.4.2 [20].5.1.5.2.1 [22].5.1.5.2.1	A station shall consider the slot busy if the channel idle/busy status is busy at the start of the slot.	Y	Y

Slot occupied detection

Requirement reference		Gnd	Air
[1].1.2.4.3 [20].5.1.5.3.1 [22].5.1.5.3.1	A slot shall be considered occupied if the channel is considered to be continuously busy for a period of at least 5 ms during the slot.	Y	Y
NOTE: The slot occupied detection is used to monitor the operations of peer stations 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 slot idle/busy state, which affects in part the station’s ability to make a random transmission.			

[40] Not required for simulations.

Signal level indication

Requirement reference		Gnd	Air
[1].1.2.4.4 [20].5.1.5.4.1 [22].5.1.5.4.1	The MAC sublayer shall accept from the physical layer an indication of the signal level.	Y	Y
NOTE:	The signal level indication is used in the periodic broadcast protocol as defined in [1].1.3.10.5.2. The measurement is for relative purposes only and need not be calibrated to any standard.		

G.1.6 Transmission processing

Requirement reference		Gnd	Air
[1].1.2.5.1 [20].5.1.6.1 [22].5.1.6.1	Bursts received from the VSS sublayer shall be forwarded to the physical layer, together with the time for transmission.	Y	Y
[1].1.2.5.2 [20].5.1.6.2 [22].5.1.6.2	A station shall begin transmissions only at the beginning of the slot boundary as determined by its local clock.	Y	Y
[1].1.2.5.3 [22].5.1.6.3	Delayed bursts[41] shall begin 4 ms after the start of the slot boundary, if the slot is idle at that point.	N	N
NOTE:	The delay allows time for other stations to begin transmitter ramp up, for the signal to travel the propagation distance, and for the slot busy detector to determine the appearance of a signal. A delayed burst can fit in a single slot and thus preserve nominal propagation guard time, even if transmission begins late. The delay may be somewhat shorter but not longer; the 4 ms value is selected to ease design and ansure robustness of the slot busy detector.		

G.1.7 Received transmission processing

Requirement reference		Gnd	Air
[1].1.2.6 [20].5.1.7.1 [22].5.1.7.1	Bursts with an invalid Cyclic Redundancy Code (CRC) shall be discarded.	Y	Y
[1].1.2.6 [20].5.1.7.2 [22].5.1.7.2	Bursts with valid CRCs shall be forwarded to the VSS sublayer, along with the received time of transmission and signal quality parameters.	Y	Y

[41] Delayed burst transmissions are not supported.

G.2 VSS sublayer

NOTE 1:	There is one VSS sub-layer entity for each VDL Mode 4 channel that is accessed by the station. The VSS sub-layer provides services to the VDL Mode 4 management entity (VME) as well as to the LME associated with other VDL Mode 4 peer systems, their associated Data Link Entities (DLEs) and the DLS. The VSS is served by the MAC that is associated with its particular VDL Mode 4 channel.
NOTE 2:	This section describes the services provided by bursts as well as some sample protocols and procedures which may be amended, extended or ignored by any specific burst application.
NOTE 3:	Other protocols may be defined for unique applications; however, it is expected that most bursts will use one of the protocols in [1].1.3.1.1. It should be noted that the various reservation fields cannot be redefined for the protocols in [1].1.3.1.1.

G.2.1 Services

Multiple access

Requirement reference		Gnd	Air
[1].1.3.1.1 [22].5.2.1.a.1	The VSS sub-layer implements protocols that enable all stations to transmit while at the same time, maintaining high system throughput, low transit delays and low probability of collisions. These protocols shall include: a) reserved access (see [1].1.3.6); b) null reservation (see [1].1.3.9); c) periodic broadcast (see [1].1.10); d) incremental broadcast (see [1].1.3.11); e) combined periodic broadcast and incremental broadcast (see [1].1.3.12); f) Big Negative Dither (BND) broadcast (see [1].1.3.13); g) unicast request (see [1].1.3.14); h) information transfer request (see [1].1.3.15); i) directed request (see [1].1.3.16); j) block reservation (see [1].1.3.17); k) response (see [1].1.3.18). l) random access (see [1].1.3.7); and m) fixed access (see [1].1.3.8).	Y (*)	Y (*)

(*) Unless explicitly specified (see below)

Error detection

Requirement reference		Gnd	Air
[1].1.3.1.2 [20].5.2.1.1.1 [22].5.2.1.1.1	The VSS sub-layer shall compute a 16 bit CRC according to ISO/IEC 3309[42] to facilitate detection by the MAC sub-layer of other peer stations of data corruption during transmission (see [1].1.2.6).	Y (*)	Y (*)

(*) The CRC computation and corresponding error detection is achieved through statistical computation based on the length of the burst transmitted.

[42] ETSI standards reference ISO/IEC 13239.

Channel congestion

Requirement reference		Gnd	Air
[1].1.3.1.3 [20].5.2.1.2.1 [22].5.2.1.2.1	The VSS sub-layer shall notify the LME sub-layer whenever channel congestion is detected (see [1].1.3.7.1.1).	Y	Y

G.2.2 Burst format

VSS burst structure

In simulations, there is no requirement to support frame and/or parameter encoding.

Indeed, PDUs (bursts, DLPDUs, etc.) may be modelled by ways of containers that convey zero, one or more fieds (each of which may convey zero, one or more subfields, such as parameter values). At any point in time, the container keeps track of the total length (in bits) of the modelled PDU (including flags, bit-stuffing, etc.) thus allowing proper restitution of all length-related effects: propagation time; occupancy on the channel; collision between bursts; applicable slot-selection procedure; etc.

The non-encoding of the corresponding bit-stream of exchanged PDUs allows simulations to save significant processing time: the encoding into a bit-stream when sending, and reversely the decoding upon receipt are time-consuming operations that are not essential for simulations (only matters the nature of the conveyed information – and not the exact way it is conveyed).

All fields of a VSS burst are modelled, and conveyed between a sender and its receiver(s), as attributes of the VSS burst container. This applies to:

- Version number ([1].1.3.2.1)
- Source address ([1].1.3.2.2)
- Message ID ([1].1.3.2.3)
- Information field ([1].1.3.2.4)
- Reservation ID fields ([1].1.3.2.5)
- Autonomous/directed flag ([1].1.3.2.6)

G.2.3 VSS sublayer parameters

General

Requirement reference		Gnd	Air
[1].1.3.3 [20].5.2.3.1.1 [22].5.2.3.1.1	VSS service system parameters shall be as described in [1].Table II-1-9.	Y	Y

[1].Table II-1-9: VSS sub-layer parameters

Symbol	Parameter name	Minimum	Maximum	Default	Increment
VS1	Number of ground quarantined slots	0 slots	15 slots	4 slots	1 slot
VS2	Minimum CCI performance	6 dB	60 dB	12 dB	1 dB
VS4	Quarantine slot re-use range	0 NM	1 000 NM	300 NM	10 NM
VS5	Maximum burst length	1 slot	16 slots	10 slots	1 slot

Parameter VS1 (number of ground quarantined slots)

Requirement reference		Gnd	Air
[1].1.3.3.1 [20].5.2.3.2.1 [22].5.2.3.2.1	The parameter VS1 shall define the number of ground quarantined slots.	Y	Y
[20].5.2.3.2.2 [22].5.2.3.2.2	Quarantined slots shall be slots which may not be used by a mobile station unless directed by a ground station.	N/A	Y
[1].1.3.6.4.1 [20].5.2.3.2.3 [22].5.2.3.2.3	With the exception of a delayed burst (see [1].1.2.5), mobile station A, will not reserve a slot or transmit on the slot boundary of the VS1 slots after a slot which has been reserved by a ground station, B, using a periodic broadcast reservation or which has been reserved by a mobile, C, using a burst with the autonomous/directed bit set to 1 and a periodic broadcast reservation field, unless the station (B or C) that has reserved the slot is at a range greater than VS4 from station A. In the case that station (B or C) that has reserved the slot is at a range greater than VS4 from station A, then station A will consider the slot to be unreserved.	N/A	Y
[1].1.3.6.4.2 [20].5.2.3.2.3	If a station receives a periodic broadcast burst with the periodic offset (po) subfield set to zero and the periodic timeout (pt) subfield set to zero, then it will maintain ground quarantine for the current slot and for M1 slots after the current slot if it had previously contained a reservation associated with the same stream. Ground quarantine behaviour for any other slots associated with the same stream will be cancelled.	Y	Y
[1].1.3.6.4.3 [20].5.2.3.2.3	A mobile station, A, will not reserve a slot or transmit in slots which have been reserved by a ground station, B, or a mobile station, C, using a block reservation, unless the station (B or C) that has reserved the slot is at a range greater than VS4 from station A, in which case station A will consider the slot to be unreserved.	N/A	Y
NOTE 1: The periodic broadcast reservation will be used to place a reservation for subsequent transmissions by the ground station. NOTE 2: Quarantine does not apply to a delayed burst. If no normal transmission is detected (i.e. no transmission starting on the slot boundary), the slot may be used for a delayed burst regardless of its perceived quarantine status. This is to allow the ground system to provide opportunities for network entry unimpeded by other traffic. However, it should be noted that delayed bursts must not be made when ground quarantine is established by using a block message.			

Parameter VS2 (minimum CCI performance)

Requirement reference		Gnd	Air
[1].1.3.3.2 [20].5.2.3.3.1 [22].5.2.3.3.1	The parameter VS2 shall be used to control the CCI conditions by which a station Y may transmit given that another station X has reserved the same slot.	Y	Y
[1].1.3.3.2 [20].5.2.3.3.2 [22].5.2.3.3.2	In the case where a station X and Y transmit in the same slot and station X's transmission is directed to another station Z, CCI conditions shall be fulfilled (a transmission from station X will not interfere with the transmissions from station Y and Z) if the ratio defined below: $$ratio = 10\log\left(\frac{dist(Y\mid Z)^2}{dist(X\mid Z)^2}\right)$$ is greater than VS2, where dist(Y/Z) is the distance between station Y and Z and dist (X/Z) is the distance between station X and station Z.	Y	Y
NOTE: This condition is applied twice to establish that the transmission between aircraft A and C will not interfere with the transmission between aircraft B and D (as described in [1].Table II-1-12).			

Parameter VS4 (quarantine slot re-use range)

Requirement reference		Gnd	Air
[1].1.3.3.3 [20].5.2.3.4.1 [22].5.2.3.4.1	The parameter VS4 shall be used to control the range at which a quarantined slot may be re-used by a distant station (see [1].1.3.6.4).	Y	Y

Parameter VS5 (maximum burst length)

Requirement reference		Gnd	Air
[1].1.3.3.4 [20].5.2.3.5.1 [22].5.2.3.5.1	The parameter VS5 shall define the maximum burst length in slots including flags and zero bits inserted for transparency.	Y	Y

G.2.4 VSS quality of service parameters

General

Requirement reference		Gnd	Air
[1].1.3.4 [20].5.2.4.1.1 [22].5.2.4.1.1	Every burst processed by the VSS sublayer for transmission shall be associated with the parameters defined in [1].Table II-1-10.	Y	Y

[1].Table II-1-10: VSS quality of service system parameters

Symbol	Parameter Name		Minimum	Maximum	Default	Increment
Q1	Priority		0	15	11	1
Q2a	Slot selection range constraint for level 1		0	1 000 NM	150 NM	1 NM
Q2b	Slot selection range constraint for level 2		0	1 000 NM	150 NM	1 NM
Q2c	Slot selection range constraint for level 3		0	1 000 NM	0 NM	1 NM
Q2d	Slot selection range constraint for level 4		0	1 000 NM	300 NM	1 NM
Q3	Replace queued data		FALSE	TRUE	FALSE	--
Q4	Number of available slots		1	20	3	1
$Q5_{min}$	VSS re-transmission parameters	minimum	0 sec	20 sec	0 sec	13.33 milliseconds
$Q5_{max}$		maximum	1 sec	20 sec	5 sec	13.33 milliseconds
$Q5_{mult}$		multiplier	1 sec	2.5 sec	1 sec	0.01 sec
$Q5_{exp}$		exponent	1	2.5	1.5	0.01
$Q5_{num}$		number of attempts	1	15	4	1
$Q5_{wait}$		maximum time to wait for a reply	1 sec	120 sec	60 sec	1 sec

Parameter Q1 (priority)

Requirement reference		Gnd	Air
[1].1.3.4.1 [20].5.2.4.2.1 [22].5.2.4.2.1	The parameter Q1 shall be the priority of the transmission and shall be as defined in [1].Table II-1-11.	Y	Y

[1].Table II-1-11: Priority levels

Message categories	Q1
Unassigned	15
Network/systems management	14
Distress communications	13
Urgent communications	12
High priority flight safety messages	11
Normal priority flight safety messages	10
Meteorological communications	9
Flight regularity communications	8
Aeronautical information service messages	7
Network/systems administration	6
Aeronautical administrative messages	5
Unassigned	4
Urgent priority administrative and UN charter communications	3
High priority administrative and state/government communications	2
Normal priority administrative	1
Low priority administrative	0
NOTE: Q1 = 15 is reserved for future use.	

Parameters Q2a to Q2d (slot selection range constraint for level n)

Requirement reference		Gnd	Air
[1].1.3.4.2 [20].5.2.4.3.1 [22].5.2.4.3.1	The parameters Q2a to Q2d shall be used to impose range constraints on the slot selection process for levels 1 to 4 defined by [1].Table II-1-12.	Y	Y

[1].Table II-1-12: Slot selection criteria

	Selection conditions		
Selection priority	**Planned transmission by station A**	**Previously reserved transmission by station B**	**Minimum distance between station A and station B**
Level 0	Any	Unreserved	Not applicable
Level 1	Broadcast or CCI protected communication with station C	CCI protected communication with station D	Q2a
Level 2	Broadcast or CCI protected communication with station C	Broadcast	Q2b
Level 3	Broadcast or CCI protected communication with station C	Broadcast or CCI protected communication with station D	Q2c
Level 4	Broadcast or CCI protected communication with station C	Any transmission	Q2d
NOTE 1: The decision criterion in this table is the distance between station A and station B. However, the requirement to check for CCI-protected communications at any given priority level requires station A to also examine the distance relationship between station B and station C, between station A and station C, between station B and station D and between station A and station D, as appropriate. It is possible to disable the selection process at any of the levels by setting the appropriate range constraint (Q21 to Q2d) to the largest possible value of 1 000 NM (see [1].Table II-1-10). NOTE 2: For certain applications, Q2d could be set to zero (Q2d = 0) so that a slot can always be chosen even if this is at the expense of another application.			

Requirement reference		Gnd	Air
[1].Table II-1-12 [20].5.2.4.3.2 [22].5.2.4.3.2	In [1].Table II-1-12, the following definitions and specifications shall apply: Station A — The station attempting to select a slot. Station B — A station that has previously reserved a slot. Station C — A station to which station A wishes to address a point-to-point communication. Station D — A station for which station B has reserved a slot for point-to-point communication. CCI protected — A point-to-point communication between two stations which fulfils the CCI conditions as defined in [1].1.3.3.2 and is therefore protected (its transmission can be heard by the intended recipient) if a third station simultaneously transmits in the same slot.	Y	Y

Parameter Q3 (replace queued data)

Requirement reference		Gnd	Air
[1].1.3.4.3 [20].5.2.4.4.1 [22].5.2.4.4.1	The parameter Q3 shall be a Boolean switch that shall be used to control queuing of repeated bursts on a congested channel.	Y	Y
[1].1.3.4.3 [20].5.2.4.4.2 [22].5.2.4.4.2	If Q3 = TRUE, then a new data field shall replace a queued data field of the same type.	Y	Y
[1].1.3.4.3 [20].5.2.4.4.3 [22].5.2.4.4.3	Otherwise, both the old and new data fields shall be transmitted.	Y	Y
NOTE: If a channel is busy and a synchronization burst containing ADS-B data cannot be transmitted, then a second synchronization burst (although with potentially different data) will overwrite the first burst.			

Parameter Q4 (number of available slots)

Requirement reference		Gnd	Air
[1].1.3.4.4 [20].5.2.4.5.1 [22].5.2.4.5.1	The parameter Q4 shall be used to control the number of slots added to the available slot list during the slot selection process (see [1].1.3.3.2).	Y	Y

Parameter Q5 (VSS retransmission parameters)

Requirement reference		Gnd	Air
[1].1.3.4.5 [21].5.3.1.1.1	The parameters Q5min, Q5max, Q5mult, Q5num and Q5wait shall control the retransmission of bursts for which an expected response has not been received (see [1].1.3.21).	Y	Y

G.2.5 Received transmission processing

Requirement reference		Gnd	Air	
[1].1.3.5.5 [20].5.2.5.1 [22].5.2.5.1	Valid bursts shall be forwarded to the appropriate VSS user, along with the time of receipt of transmission.	Y	Y	
[1].1.3.5.5 [20].5.2.5.2 [22].5.2.5.2	The received signal quality and the time of receipt of the bursts shall be passed to the VME.	Y	Y	
[1].1.3.5.1 [20].5.2.5.3 [22].5.2.5.3	A station shall be capable of recognizing and processing all possible reservation types as defined in [1].1.3.9 through [1].1.3.18.	Y	Y	
[1].1.3.5.1 [20].5.2.5.4 [22].5.2.5.4	When a station receives a burst with an unrecognized reservation type, it shall discard the burst without updating the reservation table.	N	N	(*)
[1].1.3.5.2 [20].5.2.5.5 [22].5.2.5.5	When a station receives a known reservation type with an invalid subfield, or a known reservation type with valid subfields but an invalid combination, it shall reserve the slots indicated by the valid sub-fields, and not transmit a response, nor pass the burst to a VSS user.	N	N	(*)
[1].1.3.5.3 [20].5.2.5.6 [22].5.2.5.6	When a station receives a burst with a known reservation type and a non-zero reserved subfield, it shall ignore the data in the reserved subfield.	N	N	(*)
[1].1.3.5.4 [20].5.2.5.7 [22].5.2.5.7	The current slot for a burst shall be the slot in which the received transmission begins.	Y	Y	
[1].1.3.5.4 [20].5.2.5.8 [22].5.2.5.8	The burst length (bl) shall be the number of slots across which the burst is transmitted.	Y	Y	
[1].1.3.5.5 [20].5.2.5.9 [22].5.2.5.9	If the appropriate VSS user cannot be identified (for example, the message ID is reserved for future use, or that functionality is not implemented) and the burst contains one or more reservations for the receiving station only, then the station shall transmit a GENERAL FAILURE (see [1].1.3.20) with an error type of 00 hex or 80 hex (i.e. unsupported function) in the first slot of each of the reservations.	N	N	(*)
NOTE: Current slot and burst length (bl) are used throughout the text according to protocol definitions. In the text, unless otherwise stated, references to particular slot numbers (for example, for calculating the position of new reservations) are relative to the current slot which is taken to be slot 0. If a transmission extends across a slot boundary, it is considered to occupy the slots on both sides of the boundary for reservation purposes.				

(*) Simulations never generate unrecognized reservation types, invalid subfields, invalid field combinations, VSS users that cannot be identified, etc.

G.2.6 Reserved access protocol specification

Reservation table

Requirement reference		Gnd	Air
[1].1.3.6.1.1 [20].5.2.6.1.1 [22].5.2.6.1.1	A station shall maintain a table of all reservations in the next 4 x M1 + 128 slots.	Y	Y
[1].1.3.6.1.1 [20].5.2.6.1.2 [22].5.2.6.1.2	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.	Y	Y
[1].1.3.6.1.1 [20].5.2.6.1.3 [22].5.2.6.1.3	For periodic broadcast reservations (see [1].1.3.10) and directed request reservations (see [1].1.3.16), the reservation table shall also include pointers to all other reserved slots associated with the same reservation stream.	Y	Y
[1].1.3.6.1.2 [20].5.2.6.1.4 [22].5.2.6.1.4	For the periodic broadcast protocol (see [1].1.3.10), the reservation table shall also record potential reservations, defined as the M1, 2 x M1, 3 x M1 and 4 x M1 slots after a slot for which no transmission has been decoded by the MAC layer.	Y	Y
[1].1.3.6.1.2 [20].5.2.6.1.5 [22].5.2.6.1.5	For each potential reservation, the reservation table shall include the signal level (see [1].1.2.4.4) associated with the slot and the occupancy status as defined in [1].1.2.4.3.	Y	Y
[1].1.3.6.1.2 [20].5.2.6.1.6 [22].5.2.6.1.6	Slots containing both potential reservations and reservations resulting from decoded transmissions shall be treated as if containing reservations from the decoded transmissions only.	Y	Y
[1].1.3.6.1.3 [20].5.2.6.1.7 [22].5.2.6.1.7	The reservation table shall be updated before the end of the first slot after the end of the burst.	Y	Y
[1].1.3.6.1.4 [20].5.2.6.1.8 [22].5.2.6.1.8	With the exception of transmissions in fixed transmission slots, and slots 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.	Y	Y
NOTE: Since a slot containing both a potential reservation and a reservation resulting from decoded transmission is treated as though only containing a decoded transmission, any potential reservations in subsequent superframes are effectively erased.			

Selecting slots for transmission or reservation

Requirement reference		Gnd	Air
[1].1.3.6.2 [20].5.2.6.2.1 [22].5.2.6.2.1	A station shall select slots for transmission or for reservation for later transmissions using the algorithm specified below.	Y	Y
	Specification of candidate slots		
[1].1.3.6.2.1 [20].5.2.6.2.6 [22].5.2.6.2.6	The VSS user shall specify one or more ranges of candidate slots for slot selection.	Y	Y
[1].1.3.6.2.1 [20].5.2.6.2.2 [22].5.2.6.2.2	To achieve this, the VSS user shall specify one or more groups[43] of Quality of Service parameters Q2a, Q2b, Q2c, Q2d and Q4 for slot selection.	Y	Y
[1].1.3.6.2.1 [20].5.2.6.2.3 [22].5.2.6.2.3	The station shall attempt to select slots using the first group of Quality of Service parameters.	Y	Y
[1].1.3.6.2.1 [20].5.2.6.2.4 [22].5.2.6.2.4	If slot selection is unsuccessful, the station shall use the next group and continue with successive groups until a slot has been selected.	Y	Y
[1].1.3.6.2.1 [20].5.2.6.2.5 [22].5.2.6.2.5	If, having used all groups of Quality of Service parameters, no slot has been selected, the VSS user shall be informed that slot selection has been unsuccessful.	Y	Y
	Derivation of a list of available slots		
	Slot selection criteria		
[1].1.3.6.2.2.1 [20].5.2.6.2.7 [22].5.2.6.2.7	A list of available slots shall be chosen from the candidate slots using the following rules.	Y	Y
[1].1.3.6.2.2.1.a) [20].5.2.6.2.8 [22].5.2.6.2.8	All unreserved slots shall be added to the list of available slots (shown as level 0 in [1].Table II-1-12).	Y	Y
[1].1.3.6.2.2.1.b) [20].5.2.6.2.9 [22].5.2.6.2.9	If, having completed stage [1].1.3.6.2.2.1.a), the number of available slots is less than Q4, further available slots shall be selected from slots that have been previously reserved by other stations.	Y	Y
[1].1.3.6.2.2.1.c) [20].5.2.6.2.10 [22].5.2.6.2.10	The station shall initially select from slots which obey conditions specified as level 1 in [1].Table II-1-12 until Q4 available slots have been chosen.	Y	Y
[1].1.3.6.2.2.1.d) [20].5.2.6.2.11 [22].5.2.6.2.11	If, having applied level 1 conditions, the number of available slots is still less than Q4, slot selection shall continue using level 2 conditions.	Y	Y
[1].1.3.6.2.2.1.e) [20].5.2.6.2.12 [22].5.2.6.2.12	The process shall continue using subsequent levels until Q4 slots have been selected or until all levels have been applied.	Y	Y
[1].1.3.6.2.2.1.f) [20].5.2.6.2.13 [22].5.2.6.2.13	At each level, selection shall start with slots reserved by the most distant station and proceed in decreasing range order.	Y	Y
NOTE 1: The method for specifying candidate slots is protocol dependent (see [1].1.3.9 to [1].1.3.18). NOTE 2: In addition to slots excluded because of ground quarantine (see [1].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 [1].1.2.4.3) or which the VSS user does not wish to be used at all for slot selection.			

[43] ACTS/VDL4 supports up to two groups of QOS parameters: the VSS-user's is used first, then the VSS-default.

Requirement reference		Gnd	Air
	Recommendation		
[1].1.3.6.2.2.2.1 [20].5.2.6.2.14 [22].5.2.6.2.14	In selecting the list of available slots at level 0, priority should be given to candidate slots which are not reserved for transmission on any channel monitored by the station, and which also do not violate quarantine constraints (see [1].1.3.6.4) on the desired transmit channel.	Y	Y
[1].1.3.6.2.2.2.2 [22].5.2.6.2.14aa	A mobile station should exclude from consideration any slots which have been previously reserved for a point-to-point transmission, on any channel, where it is the intended destination.	N	N
	Additional considerations for slot selection for transmission		
[1].1.3.6.2.2.3 [22].5.2.6.2.14a	When selecting the list of available slots for transmission in a channel for mobile station A or for another mobile station B, station A shall exclude from consideration the specific slots which it knows are reserved for transmission for the intended station (either A or B) on other channels monitored by station A.	N	N
	Additional constraints applying to Global Signalling Channels (GSCs)		
[1].1.3.6.2.3 [22].5.2.6.2.14b	On channels designated as GSCs (see Annex 10 - Aeronautical Telecommunications, Volume III, Part I Digital Data Communication System, chapter 6, 6.9.2.2.1), mobile stations maintaining primary or secondary time shall exclude the first V66 (see [1].1.3.17.5.2) slots of every UTC second.	Y	Y
[1].1.3.6.2.3 [22].5.2.6.2.14c	The first V66 slots after every UTC second shall comprise the Virtual Link Management Channel (VLMC) and shall be allocated for ground station use only.	Y	Y
	Selection of slots from available slots		
[1].1.3.6.2.4 [20].5.2.6.2.15 [22].5.2.6.2.15	If, having completed the derivation of a list of available slots, the number of available slots is zero, no slot shall be selected and the VSS user shall be informed that slot selection was unsuccessful.	Y	Y
[1].1.3.6.2.4 [20].5.2.6.2.16 [22].5.2.6.2.16	If the number of available slots is greater than or equal to 1, a slot shall be chosen from the list of available slots such that the probability of choosing a given slot is the same as the probability of choosing any other slot.	Y	Y
	Selection of slots for burst lengths greater than 1		
[1].1.3.6.2.5 [20].5.2.6.2.17 [22].5.2.6.2.17	For burst lengths greater than one (bl > 1), the process specified in [1].1.3.6.2.2 shall be applied to continuous blocks of slots of length equal to the burst length.	Y	Y
[1].1.3.6.2.5 [20].5.2.6.2.18 [22].5.2.6.2.18	A block of slots shall be regarded as available at a particular level number (see [1].Table II-1-12) if all slots within the block are available at the same or lower level number.	Y	Y
[1].1.3.6.2.5 [20].5.2.6.2.19 [22].5.2.6.2.19	The procedure described in [1].1.3.6.2.4 shall then be used to select one of the available blocks.	Y	Y
	Limits on selection of reserved slots		
[1].1.3.6.2.6 [20].5.2.6.2.20 [22].5.2.6.2.20	A station which has selected a slot that was reserved by another station shall not select another slot reserved by that station within M1 - 1 slots after the selected slot.	N	N

Reserved transmissions

Requirement reference		Gnd	Air	
[1].1.3.6.3 [20].5.2.6.3.1 [22].5.2.6.3.1	When a station has a burst to transmit for which it has a reservation, it shall transmit the scheduled data in the reserved slots, except as noted below.	Y	Y	
	Unavailable data			
[1].1.3.6.3.1 [20].5.2.6.3.2 [22].5.2.6.3.2	If the data for a burst, for which a slot was reserved by another station, is unavailable when it is time to transmit, then the station shall send a GENERAL FAILURE (see see [1].1.3.20).	N	N	([44])
	Reservation no longer valid			
[1].1.3.6.3.2 [20].5.2.6.3.3 [22].5.2.6.3.3	A station shall check that a reservation is valid according to the procedures of see [1].1.3.6.5 before making a transmission.	N	N	([45])

Reservation conflicts

Requirement reference		Gnd	Air
[1].1.3.6.5 [20].5.2.6.4.1 [22].5.2.6.4.1	If a station, A, receives a burst containing a reservation from another station, B, for a slot which has already been reserved for station A to transmit, then station A shall take the following action:	Y	Y
[1].1.3.6.5.a) [20].5.2.6.4.2 [22].5.2.6.4.2	If the conflicting reservation from station B also requires station A to transmit, then station A shall transmit: (i) the response with the higher priority (as determined by Q1); or (ii) the first requested transmission in the case of equal priority (see note); or else	Y	Y
[1].1.3.6.5.b) [20].5.2.6.4.3 [22].5.2.6.4.3	If station A no longer requires to transmit in the existing reservation, or does not have the necessary information to transfer, then it shall not transmit in the slot, or else;	Y	Y
[1].1.3.6.5.c) [20].5.2.6.4.4 [22].5.2.6.4.4	If the existing reservation for station A to transmit was made by a station other than A (i.e. by a unicast request (sdf = 0), information transfer, or directed request reservation), then A shall transmit in the slot in accordance with the existing reservation; or else	Y	Y
[1].1.3.6.5.d) [20].5.2.6.4.5 [22].5.2.6.4.5	If the existing reservation for station A to transmit was made by A itself, then A shall apply the procedure described in [1].1.3.6.2.2 to determine whether, in the knowledge of the reservation made by station B, the slot is available at any level 1, 2, 3 or 4, using the same values of Q2 and other parameters as originally used to select the slot or other VSS user supplied QoS parameters for conflict resolution;	Y	Y
[1].1.3.6.5.d) [20].5.2.6.4.6 [22].5.2.6.4.6	If the slot is determined to be available by this process, then A shall transmit according to its existing reservation;	Y	Y
[1].1.3.6.5.d) [20].5.2.6.4.7 [22].5.2.6.4.7	If the slot is no longer available, the actions specified in [1].Table II-1-13 shall be performed.	Y	Y
NOTE: The rules determine the action that a station takes in the event that a reservation conflict is detected. This is a normal event which is expected to occur as a result of slot reuse under CCI protection. In the event of a conflict, the slot selection criteria are generally reapplied to determine whether or not the slot could still have been selected in the knowledge of the new conflicting reservation. Generally, a station required to transmit in a slot that was reserved for it by another station will always transmit, since it cannot be assumed to have possession of the necessary information to determine the optimum action.			

[44] No such cases ever happen in simulations.

[45] Conflict resolution as described in [1].1.3.6.5 is performed at the time a reservation conflict is detected, i.e. upon receipt of the conflicting reservation. If a conflict resolution is in favour of another station, the reservation previously made by the recipient is removed, along with the corresponding transmission (thus making this requirement useless).

[1].Table II-1-13: 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 [1].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.
Periodic broadcast	Periodic broadcast (autonomous/directed), directed request, slots reserved by ground quarantine (see [1].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.
Incremental broadcast	Any	Do not transmit in the existing reservation. Make the transmission in an alternative slot by random access ([1].1.3.7).
Unicast request (sdf = 1), or information transfer	Any protocol	Do not transmit in the existing reservation. Apply the re-transmission procedures ([1].1.3.21).

Transmission conflicts for mobile stations

Requirement reference		Gnd	Air
[1].1.3.6.6 [22].5.2.6.5.1	If a mobile station is requested to transmit in the same slot on different channels, then the station shall take the following action:	N/A	N [46]
[1].1.3.6.6 [22].5.2.6.5.2	a) If there is only one transmission with the highest priority among the required transmissions, then the station shall transmit this highest priority transmission.	N/A	N
[1].1.3.6.6 [22].5.2.6.5.3	b) If there is only one ground-initiated transmission among the transmissions with the same highest priority, then the station shall transmit this ground-initiated transmission.	N/A	N
[1].1.3.6.6 [22].5.2.6.5.4	c) If there is more than one ground-initiated transmission among the transmissions with the same highest priority, then the station shall transmit the last requested of these ground-initiated transmissions.	N/A	N
[1].1.3.6.6 [22].5.2.6.5.5	d) If there are no ground-initiated transmissions among the transmissions with the same highest priority, then the station shall transmit the first requested transmission.	N/A	N

[46] In ACTS/VLD4, a mobile station is never requested to transmit in the same slot on a different channel.

G.2.7 Random access protocol specification

General

Requirement reference		Gnd	Air
[1].1.3.7 [20].5.2.7.1.1 [22].5.2.7.1.1	The station shall implement a non-adaptive p-persistent algorithm to allow equitably all stations the opportunity to transmit while maximizing system throughput, minimizing transit delays, and minimizing collisions.	Y	Y
NOTE: Transmissions which use the random access procedures may be used to place reservations for future transmissions that also use the reserved access procedures ([1].1.3.6) or they may be "one-off" transmissions which place no reservations and which will conform to either the null reservation burst format ([1].1.3.9.1) or the response protocol burst format ([1].1.3.18.1).			

Random access parameters

Requirement reference		Gnd	Air
[1].1.3.7.1 [20].5.2.7.2.1 [22].5.2.7.2.1	Random access parameters shall be as described in [1].Table II-1-14.	Y	Y

[1].Table II-1-14: Random access VSS system parameters

Symbol	Parameter name	Minimum	Maximum	Default	Increment
TM2	Channel busy timer	20 slots	4 500 slots	1 500	20 slots
P	Persistence	1/256	1	64/256	1/256
VS3	Maximum number of access attempts	1	65 536	24	1

Requirement reference		Gnd	Air
	Timer TM2 (channel busy timer)		
[1].1.3.7.1.1 [20].5.2.7.2.2 [22].5.2.7.2.2	Timer TM2 indicates the number of slots (TM2) that a sub-layer shall wait after receiving a request to transmit.	Y	Y
[1].1.3.7.1.1 [20].5.2.7.2.3 [22].5.2.7.2.3	This timer shall be started if it is not already running, when the VSS sub-layer receives a request for random transmission.	Y	Y
[1].1.3.7.1.1 [20].5.2.7.2.4 [22].5.2.7.2.4	Upon a successful random transmission access attempt, the timer shall be cleared if the random transmit queue is empty and reset if it is not empty.	Y	Y
[20].5.2.7.2.5 [22].5.2.7.2.5	When the timer expires, the VSS user shall be informed that the channel is congested.	Y	Y
	Parameter p (persistence)		
[1].1.3.7.1.2 [20].5.2.7.2.6 [22].5.2.7.2.6	Parameter p shall be the probability that the station will transmit on any random access attempt.	Y	Y
[1].1.3.7.2.1.3 [20].5.2.7.2.7 [22].5.2.7.2.7	If the station is able to select a slot, then the station shall transmit on the slot boundary with probability p.	Y	Y
	Counter VS3 (maximum number of access attempts)		
[1].1.3.7.1.3 [20].5.2.7.2.8 [22].5.2.7.2.8	Counter VS3 shall be used to limit the maximum number of random access attempts (VS3) that a station will make for any transmission request.	Y	Y
[1].1.3.7.1.3 [20].5.2.7.2.9 [22].5.2.7.2.9	This counter shall be cleared upon system initialization, Timer TM2 expiring, or a successful access attempt.	Y	Y
[1].1.3.7.1.3 [20].5.2.7.2.10 [22].5.2.7.2.10	The counter shall be incremented after every unsuccessful random access attempt.	Y	Y
[1].1.3.7.1.3 [20].5.2.7.2.11 [22].5.2.7.2.11	When the counter reaches the maximum number of random access attempts, or when it has been cleared due to expiration of TM2, authorization to transmit shall be granted as soon as the channel becomes available.	Y	Y

Random access procedures

Requirement reference		Gnd	Air	
	Random access procedures			
[1].1.3.7.2.1.1 [20].5.2.7.3.1 [22].5.2.7.3.1	When the station has one or more bursts to transmit for which it does not have a reservation, it shall use a p-persistent algorithm as defined as follows.	Y	Y	
[1].1.3.7.2.1.1.a) [20].5.2.7.3.2 [22].5.2.7.3.2	Access attempts shall only be made and transmission shall only begin on a slot boundary of available slots.	Y	Y	
[1].1.3.7.2.1.1.a) [20].5.2.7.3.3 [22].5.2.7.3.3	A station shall regard a slot or block of slots as available for a random transmission if it conforms to the criteria of any of Levels 0 through 2 in [1].Table II-1-12 using default or VSS user-supplied quality of service parameters.	Y	Y	
[1].1.3.7.2.1.1.b) [20].5.2.7.3.4 [22].5.2.7.3.4	Transmission shall not begin if the station has not previously made or received a reservation for the prior slot, and the slot is busy as defined in [1].1.2.4 at the slot boundary.	Y	Y	
[1].1.3.7.2.1.2 [20].5.2.7.3.5 [22].5.2.7.3.5	If the station is unable to select a slot, this shall be regarded as an unsuccessful random access attempt.	Y	Y	
[1].1.3.7.2.1.3	If the station is able to select a slot, then the station shall transmit on the slot boundary with probability p (as defined in [1].1.3.7.1.2).	Y	Y	
	Random access procedures for delayed transmissions			
[1].1.3.7.2.2.1 [22].5.2.7.3.5a	Delayed transmissions shall use a p-persistent algorithm defined as follows:	N	N	
[1].1.3.7.2.2.1 [22].5.2.7.3.5b	a) transmissions shall be delayed relative to the slot boundary in accordance with [1].1.2.5; and	N	N	
[1].1.3.7.2.2.1 [22].5.2.7.3.5c	b) a station shall not start a transmission if the channel idle/busy status (see Annex 10 – Aeronautical Telecommunications, Volume III, Part I – Digital Data Communication System, Chapter 6, 6.9.5.3) is busy at the intended (delayed) start time.	N	N	
[1].1.3.7.2.2.2 [22].5.2.7.3.5d	If the station is unable to select a slot, this shall be regarded as an unsuccessful random access attempt.	Y	Y	
[1].1.3.7.2.2.3 [22].5.2.7.3.5e	If the station is able to select a slot, then the station shall transmit on the slot boundary with probability p (as defined in [1].1.3.7.1.2).	Y	Y	
	Recommendation			
[1].1.3.7.2.3.1 [20].5.2.7.3.6 [22].5.2.7.3.6	Whenever possible, a station should use the reserved access protocols described in [1].1.3.6 to reserve slots for new transmissions by adding reservation fields to transmissions for which slots have already been reserved.	N	N	([47])
[1].1.3.7.2.3.1 [20].5.2.7.3.7 [22].5.2.7.3.7	The random access protocol should be used only if there is no suitable opportunity to reserve a slot.	Y	Y	
	Recommendation			
[1].1.3.7.2.3.2 [20].5.2.7.3.8 [22].5.2.7.3.8	Whenever possible, if there has been no previous reservation, a ground station should use ground quarantined slots for transmission.	Y	N/A	
[1].1.3.7.2.3.2 [20].5.2.7.3.9 [22].5.2.7.3.9	The random access protocol should be used only if there is no suitable opportunity to use ground quarantined slots.	Y	N/A	

[47] There is no specific feature in ACTS/VDL4 to support this requirement. Yet, it is partially satisfied by the support of a number of DLS requirements and recommendations (including DLPDU linkage) that put a reservation on an outgoing transmission, in the case there is additional message left in the transmit queue.

	Transmit queue management		
[1].1.3.7.2.4 [20].5.2.7.3.10 [22].5.2.7.3.10	There shall be a single queue for all random transmissions which do not have reserved slots for transmission.	Y	Y
[1].1.3.7.2.4 [20].5.2.7.3.11 [22].5.2.7.3.11	This queue shall be sorted in priority order, with a higher value of Q1 being transmitted before a lower value of Q1.	Y	Y
[1].1.3.7.2.4 [20].5.2.7.3.12 [22].5.2.7.3.12	If Q3 is TRUE, then the queue shall be searched to determine if a burst of the same type has been queued.	Y	Y
NOTE: Consider the case where a station intends to apply a p-persistent algorithm for random transmission at the start of slot k. If the prior slot [k−1] is reserved and slot k is unreserved or effectively unreserved, the station may be confident that the transmission in slot [k−1] will terminate and garble will not occur. However, if slot [k−1] is unreserved (according to the reservation table of the station) but nonetheless busy, the station has no way of knowing whether the transmission will terminate or continue. So in this case, a physical layer measurement is necessary to ensure that the transmission has terminated. Since the measurement process takes finite time, an apparently unreserved transmission which ends close to the end of slot [k−1] may forestall a random transmission in slot k. This is unavoidable.			

G.2.8 Fixed access protocol specification

General

Requirement reference		Gnd	Air
[1].1.3.8 [20].5.2.8.1.1	A ground station shall be capable of being pre-programmed either to not transmit in certain slots with starting times expressed in UTC or to transmit specific transmissions in specific slots with starting times expressed in UTC (without necessarily announcing a reservation).	N[48]	N/A

Recommendation

Requirement reference		Gnd	Air
[1].1.3.8.1 [20].5.2.8.2.1	The user should specify the use of an appropriate reservation protocol to protect future fixed transmissions.	N	N
NOTE 1: The user will be able to specify a time or slot for a particular transmission and can also specify a reservation protocol to protect the next fixed transmission. For example, the user could specify a certain ground transmission at a certain time and then specify the use of the periodic reservation block to reserve the same slot in the next minute. NOTE 2: The ground infrastructure service provider is able to use this fixed access protocol and the superframe block reservation protocol (see [1].1.3.17.7.1) in order to organize a series of coordinated reserved slots for ground transmissions.			

G.2.9 Null reservation protocol specification

Null reservation burst format (see [1].1.3.9.1)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

[48] This feature is not supported in ACTS/VDL4, as the only applicable is a recommendation.

G.2.10 Periodic broadcast protocol specification

Periodic broadcast reservation burst format (see [1].1.3.10.1)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

Periodic broadcast timers

Requirement reference		Gnd	Air
	Timer TV11 (reservation hold timer)		
[1].1.3.10.2.1 [20].5.2.10.2.1 [22].5.2.10.2.1	The timer TV11 shall control the number of successive superframes which will use the same slot for transmission (see [1].1.3.10.5) before moving to a new slot.	Y	Y
[1].1.3.10.2.1 [20].5.2.10.2.2 [22].5.2.10.2.2	There shall be one TV11 timer for each slot used for periodic broadcasts.	Y	Y

Periodic broadcast parameters

Requirement reference		Gnd	Air
[1].1.3.10.3 [20].5.2.10.3.1 [22].5.2.10.3.1	The periodic broadcast protocol shall implement the system parameters defined in [1].Table II-1-18.	Y	Y

[1].Table II-1-18: Periodic broadcast VSS system parameters

Symbol	Parameter name	Minimum	Maximum	Recommended default	Increment	
TV11min	Reservation hold timer minimum value	0 superframes	15 superframes	4 superframes	1 superframe	
TV11max	Reservation hold timer maximum value	1 superframe	16 superframes	8 superframes	1 superframe	
V11	Nominal periodic rate	1 per superframe	60 per superframe	1 per superframe	1 per superframe	([49])
V12	Periodic dither range	(2/M1) x V11	1.00	0.10	0.01	

[49] In ACTS/VDL4, the V11 parameter may possibly be set to 0 (air-side only), to support simulations where point-to-point communications take place on a dedicated channel.

Requirement reference		Gnd	Air
[1].Table II-1-18 [20].5.2.10.3.2 [22].5.2.10.3.2	TV11 min shall be less than or equal to TV11 max.	Y	Y
[1].Table II-1-18 [20].5.2.10.3.3 [22].5.2.10.3.3	The VSS user shall provide any of the parameters TV11 min, TV11 max, V11, V12 and Quality of Service (QoS) parameters (Q2a to Q2d and Q4) for which the default values are not desired.	Y	Y
	Parameters TV11min and TV11max (reservation hold timer minimum and maximum values)		
[1].1.3.10.3.1 [20].5.2.10.3.4 [22].5.2.10.3.4	Parameters TV11min and TV11max shall be used to determine the start value for the TV11 timer, consistent with the procedure defined in [1].1.3.10.5.4.	Y	Y
	Parameter V11 (nominal periodic rate)		
[1].1.3.10.3.2 [20].5.2.10.3.5 [22].5.2.10.3.5	The parameter V11 shall be the number of times per superframe that a VSS user will transmit a burst.	Y	Y
	Parameter V12 (periodic dither range)		
[1].1.3.10.3.3 [20].5.2.10.3.6 [22].5.2.10.3.6	The parameter V12 shall define the range for candidate slots on either side of the nominal slot (see [1].1.3.10.5.1) from which the station shall choose a slot or group of slots to be reserved for transmission once the TV11 timer expires.	Y	Y
[1].1.3.10.3.3 [20].5.2.10.3.7 [22].5.2.10.3.7	V12 shall be specified as a fraction of the nominal periodic rate.	Y	Y
NOTE: The selected slot may be chosen from a range between the nominal slot {− (V12/2) x (M1/V11)} and the nominal slot {+ (V12/2) x (M1/V11)}. If this range is greater than ± 127, then the selected slot may be chosen from a range between nominal slot −127 and the nominal slot +127.			

Periodic broadcast reception procedures

Requirement reference		Gnd	Air
[1].1.3.10.4.1 [20].5.2.10.4.1 [22].5.2.10.4.1	Upon receipt of a burst containing a periodic broadcast reservation, the station shall update its reservation table and carry out the actions as specified in [1].Table II-1-19.	Y	Y

[1].Table II-1-19: Action on receipt of periodic broadcast reservation burst

Periodic offset (po)	Periodic timeout (pt)	Action
0	0	No reservation (see note 1)
Any except 0	0, 1 or 2	Reserve the following slots for the source to broadcast: if pt = 1 or 2 then for j = 1 to pt, the slots equal to (j x M1) through (bl - 1 + (j x M1)) after the first slot of the received burst AND for j = pt + 1 to 4, the slots equal to (po + (j x M1)) through (bl - 1 + (po + (j x M1))) slots after the first slot of the received burst
0	1 or 2	Reserve the following slots for the source to broadcast: for j = 1 to pt, the slots equal to (j x M1) through (bl - 1 + (j x M1)) after the first slot of the received burst
any	3	Reserve the following slots for the source to broadcast: for j = 1 to 4, the slots equal to (j x M1) through (bl - 1 + (j x M1)) after the first slot of the received burst. (see note 2)
NOTE 1: Reservation format is the same as null reservation (see [1].1.3.9). NOTE 2: The interpretation of the periodic offset subfield in the case of periodic timeout = 3 and io ≠ 0 binary is described in [1].1.3.12 and [1].1.3.12.1.		

Requirement reference		Gnd	Air
[1].1.3.10.4.1 [20].5.2.10.4.2 [22].5.2.10.4.2	All reservations associated with a single periodic broadcast reservation burst shall be known as a stream.	Y	Y
[1].1.3.10.4.2 [20].5.2.10.4.3 [22].5.2.10.4.3	The actions defined in [1].Table II-1-19 shall cancel any previous reservations for the same stream.	Y	Y
[1].1.3.10.4.3 [20].5.2.10.4.4 [22].5.2.10.4.4	If a station was expecting to receive a transmission from a peer station containing a periodic broadcast reservation, but receives a transmission from the peer station containing an incremental broadcast reservation (see [1].1.3.11) or a unicast request with the source/destination flag (sdf) set equal to 1 (see [1].1.3.14), the station shall cancel the periodic broadcast reservation stream for the peer station.	Y	Y

Periodic broadcast transmission procedures

Requirement reference		Gnd	Air
	Selection of nominal slots		
[1].1.3.10.5.1.1 [20].5.2.10.5.1 [22].5.2.10.5.1	When periodic broadcast transmissions are used on a frequency which is not subject to directed-slot reservations (see [1].1.3.16.1.1), a station shall select nominal slots (n_slot) which form a periodic sequence in time, with a variation of no more than ±1 slot as required to accommodate the constraints imposed by the nominal reporting rate for the application and the slot rate on the channel.	Y	Y
[1].1.3.10.5.1.2 [20].5.2.10.5.2 [22].5.2.10.5.2	When operating with a mixture of directed-slot reservations, autonomous, and/or directed-rate reservations (see [1].1.3.16.1.1) for a given VSS user-application which requires periodic broadcast transmissions, a station shall select nominal slots (n_slot) for the autonomous or directed rate which form a periodic sequence in time, considering all frequencies used, with a variation of no more than ±1 slot as required in order to accommodate the constraints imposed by the nominal update rate for the application and the slot rate on the channel.	Y	Y
NOTE 1: For an application that requires periodic broadcast transmissions on multiple frequencies and for which no directed slot reservations have been received, the aggregate of all required transmissions should be used when calculating the nominal update rate (nr). Example 1: Two frequencies have a required nr of once per 10 seconds on each frequency. In this case, the nominal slots (n_slots) should be interleaved and equally spaced to achieve an aggregate nr of once per 5 seconds (i.e. considering the two channels together). Example 2: Two frequencies have a required nr of once per 15 seconds on frequency F1 and once per 5 seconds on frequency F2. In this case, the aggregate nr should be once per 3.75 seconds, with three successive n_slots on F2 spaced 3.75 seconds apart, followed by a 7.5 second gap centred on a n_slot for F1, followed by another three successive n_slots on F2 etc. NOTE 2: A station may shift all the nominal slots (n_slots) associated with an application's autonomous or directed rate reservations forward or backward in time without changing their relative positions in order to enhance the likelihood of finding appropriate transmission slots for the application as a whole (i.e. within the dither bands surrounding each n_slot). NOTE 3: A station may shift individual slots or sets of slots as required in order to satisfy the needs in the selection of nominal slots (n_slots). This may be required, for example, if the application adds a new frequency or if the nominal update rate (nr) on one of the existing frequencies is changed in real time (i.e. with a directed rate request). NOTE 4: Paragraph [1].1.3.10.5.1 is relevant for transmissions using periodic reservations. It does not apply to transmissions using other reservation types or random transmissions. For example, transmissions made using random and incremental protocols are excluded.			

Requirement reference		Gnd	Air
	Selection of slots for a periodic broadcast transmission		
[1].1.3.10.5.2 [20].5.2.10.5.3 [22].5.2.10.5.3	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:	Y	Y
[1].1.3.10.5.2.a) [20].5.2.10.5.4 [22].5.2.10.5.4	The station shall use the slot selection procedure specified in [1].1.3.6.2 using all slots that are within (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.	Y	Y
[1].1.3.10.5.2.b) [20].5.2.10.5.5 [22].5.2.10.5.5	When applying the slot selection procedure specified in [1].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 [1].1.2.4.3.	Y	Y
[1].1.3.10.5.2.b) [20].5.2.10.5.6 [22].5.2.10.5.6	Selections at level 0 shall select from slots containing potential reservations associated with unoccupied slots in increasing order of signal level as defined in [1].1.2.4.4.	Y	Y
[1].1.3.10.5.2.c) [20].5.2.10.5.7 [22].5.2.10.5.7	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 [1].1.2.4.4.	Y	Y
[1].1.3.10.5.2.d) [20].5.2.10.5.8 [22].5.2.10.5.8	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 three.	Y	Y
NOTE: The station tries to find unreserved slots in the range of [(V12 × M1)/V11] on either side of the nominal slot (n_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 protcol for subsequent superframes. If slot selection is unsuccessful by the end of level two, the potential reservations are then added back into the candidate range and selected in order of increasing signal level.			

Requirement reference		Gnd	Air
	Calculation of slot availability		
[1].1.3.10.5.3 [20].5.2.10.5.9 [22].5.2.10.5.9	After selection of a new current transmission slot, the station shall compute the slot availability (s_avail), indicating how many consecutive superframes are available until the equivalent slot is reserved by another user.	Y	Y
[1].1.3.10.5.3 [20].5.2.10.5.10 [22].5.2.10.5.10	The value of s_avail shall indicate the slot (ct_slot + s_avail × M1) which is reserved by another user, and range from 1 (for a slot that is reserved in the next superframe) to 4 (for slots that currently have no reservation for at least 3 superframes)	Y	Y
[1].1.3.10.5.3 [20].5.2.10.5.11 [22].5.2.10.5.11	The calculation of s_avail shall use the following rules:	Y	Y
[1].1.3.10.5.3.a) [20].5.2.10.5.12 [22].5.2.10.5.12	If the current transmission slot has not been previously reserved, s_avail shall be the number of superframes that are left before the equivalent slot is reserved;	Y	Y
[1].1.3.10.5.3.b) [20].5.2.10.5.13 [22].5.2.10.5.13	If the current transmission slot has been previously reserved by a station, s_avail shall be the number of superframes that are left before the equivalent slot is reserved by a different user.	Y	Y
	Transmission in a new slot		
[1].1.3.10.5.4 [20].5.2.10.5.14 [22].5.2.10.5.14	If there is no prior reservation or if the station is using for the first time a slot for which there has been a prior reservation, the station shall start the timer TV11 at a value equal to s_avail, if s_avail = 1, 2 or 3, and otherwise equal to a random value uniformly chosen between TV11 min and TV11 max.	Y	Y
	Transmission for TV11 greater than 3		
[1].1.3.10.5.5 [20].5.2.10.5.15 [22].5.2.10.5.15	If the TV11 timer is greater than 3 and there is no requirement to associate the current transmission with an incremental reservation, the station shall transmit a burst containing a periodic broadcast reservation in the current transmission slot with io = 0 and pt = 3.	Y	Y
[1].1.3.10.5.5 [20].5.2.10.5.16 [22].5.2.10.5.16	After transmission, the timer TV11 shall be decremented by one and the current transmission slot shall be incremented by M1.	Y	Y

Requirement reference		Gnd	Air
	Reservation of a new slot for TV11 equal to 1, 2, or 3		
[1].1.3.10.5.6 [20].5.2.10.5.17 [22].5.2.10.5.17	If the TV11 timer is equal to 1, 2 or 3 and if the VSS user requires that periodic broadcast reservations are maintained after the current transmission slot reservation expires, the station shall reserve a future transmission slot (ft_slot) for subsequent transmissions.	Y	Y
[1].1.3.10.5.6 [20].5.2.10.5.18 [22].5.2.10.5.18	If a future transmission slot has already been selected, there shall be no further slot selection.	Y	Y
[1].1.3.10.5.6 [20].5.2.10.5.19 [22].5.2.10.5.19	Otherwise, selection of ft_slot shall be carried out using the procedure set out in [1].1.3.10.5.2 using all slots that are within (V12/2) × (M1/V11) of n_slot and within 127 slots of n_slot and within 127 slots of ct_slot, except slot (ct_slot + TV11 × M1), as candidate slots.	Y	Y
	Transmission for TV11 equal to 1, 2 or 3		
[1].1.3.10.5.7.1 [20].5.2.10.5.20 [22].5.2.10.5.20	If the TV11 timer is equal to 1, 2 or 3 the station shall transmit a burst containing a periodic broadcast reservation in the current transmission slot with po = (ft_slot - ct_slot) and pt = TV11 - 1.	Y	Y
[1].1.3.10.5.7.2 [20].5.2.10.5.21 [22].5.2.10.5.21	If a future transmission slot has not been selected and the VSS user does not require the reservation to be maintained, the value of po shall be set to zero.	Y	Y
[1].1.3.10.5.7.3 [20].5.2.10.5.22 [22].5.2.10.5.22	After transmission, the timer TV11 shall be decremented and the current transmission slot set equal to ct_slot + M1.	Y	Y
	TV11 equal to zero		
[1].1.3.10.5.8.1 [20].5.2.10.5.23 [22].5.2.10.5.23	If the TV11 timer is equal to zero, and the VSS user requires a reservation to be maintained, then if a new slot has not been selected for further periodic broadcasts, the station shall select a new current transmission slot using the procedures set out in [1].1.3.10.5.2.	Y	Y
[1].1.3.10.5.8.1 [20].5.2.10.5.24 [22].5.2.10.5.24	If a new slot has been selected for further periodic broadcasts, the station shall set the current transmission slot equal to the future transmission slot.	Y	Y
[1].1.3.10.5.8.2 [20].5.2.10.5.25 [22].5.2.10.5.25	The station shall start to transmit in the new current transmission slot carrying out the procedures set out in [1].1.3.10.5.3 to [1].1.3.10.5.8.	Y	Y
[1].1.3.10.5.8.3 [20].5.2.10.5.26 [22].5.2.10.5.26	If the VSS user does not require a reservation to be maintained, no further action shall be taken.	Y	Y
	Reservation cancellation		
[1].1.3.10.5.9 [20].5.2.10.5.27 [22].5.2.10.5.27	A station wishing to cancel a stream or reservations for its own transmissions, in the absence of a reservation conflict, shall transmit a periodic broadcast reservation burst with po = 0 and pt = 0 in the next reserved slot and the timer TV11 shall be cleared.	Y	Y
[1].1.3.10.5.9 [20].5.2.10.5.28 [22].5.2.10.5.28	A station receiving such a burst shall clear all reservations known to be associated with the stream.	Y	Y
NOTE 1: The reservation for a new slot is maintained for TV11 superframes unless slot availability (s_avail) indicates that only 1, 2 or 3 superframes are available before another station has placed a reservation. NOTE 2: The process in [1].1.3.10.5.6 selects a new slot to which the periodic broadcast transmission will move in the TV11 superframes after the current transmission slot (ct_slot). This new slot will occupy a different position in the superframe to the ct_slot. NOTE 3: Because all existing reservations for a stream are cancelled on receipt of a periodic reservation burst and are replaced according to the reservation information contained in the burst (see [1].1.3.10.4), this action has the effect of cancelling the whole stream. NOTE 4: Reservation conflicts are mediated in accordance with [1].1.3.6.5, and the requirement to transmit a reservation cancellation (i.e. po = 0 and pt = 0) does not apply if the transmission would be disallowed by the considerations outlined in [1].1.3.6.5.			

G.2.11 Incremental broadcast protocol specification

The incremental broadcast protocol is intended for those VSS users which are transmitting multiple times per minute, but only for a minute or two. A burst reserves a number of slots for a time later in the same superframe. The number of slots reserved is equal to the burst length of the burst containing the reservation.

Not required for targeted simulations, the incremental broadcast protocol is not supported.

G.2.12 Combined periodic broadcast and incremental broadcast protocol specification

The periodic broadcast reservation can be combined with an incremental broadcast reservation when the periodic broadcast timer (TV11) is greater than 3, enabling the station to reserve a fourth slot up to 1020 slots in the future (as well as three slots in the subsequent superframes). A station may therefore use the opportunity presented by a combined periodic broadcast and incremental broadcast to reserve a slot for a different VSS user which happens to be in the random access queue or to improve net entry performance by reserving both in the next superframe (periodic broadcast) and this superframe (incremental broadcast).

Not required for targeted simulations, the combination of periodic broadcast with incremental broadcast protocol is not supported.

G.2.13 Big negative dither (BND) broadcast protocol specifications

The BND can be used by a VDL Mode 4 station intending to enter a VDL Mode 4 channel/network (i.e. begin transmitting synchronization bursts on an autonomous basis), in cases where:

a) the station has listened to the channel for a few seconds but has not yet built a complete reservation table;

b) the station has either: i) fewer current reservations for synchronization bursts than required; or ii) a sufficient number of reservations, but one or more of them is about to expire (pt = 0); and

c) the station wishes to initiate or continue periodic streams using the reservation opportunities presented by these existing reservations.

The BND can be transmitted in a normal or delayed burst. The BND can also be used in the context of a normal stream of synchronization bursts, to meander a stream outside the existing maximum dither range (e.g. when the flow channel must be adjusted).

Not required for targeted simulations, the BND broadcast protocol is not supported.

G.2.14 Unicast request protocol specification

This protocol is intended for a VSS user which requires (a) a response from a peer VSS user in a reserved slot; (b) a slot to be reserved for a transmission to a peer, or (c) a slot to be reserved to make a broadcast transmission. In the case of (c), the procotol is a more flexible version of the incremental broadcast protocol, supporting reservations of variable length on user defined channels.

Unicast request reservation burst format

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

Unicast request parameters

Requirement reference		Gnd	Air
[1].1.3.14.2 [20].5.2.14.1a.1 [21].5.3.2.1.1	The unicast request protocol shall implement the system parameters as defined in [1].Table II-1-28.	Y	Y

[1].Table II-1-28: Unicast request VSS system parameters

Symbol	Parameter name	Minimum	Maximum	Recommended default	Increment
V32	Minimum response delay	2 slot	500 slots	20 slots	1 slot
V33	Maximum response delay	2 slot	4 095 slots	1 000 slots	1 slot
V34	Source/destination control	0	1	0	1
V35	Broadcast control	0	1	0	1
V36	Length of reserved block	1 slot	256 slots	N/A	1 slot

Requirement reference		**Gnd**	**Air**	
[1].1.3.14.2 [20].5.2.14.1a.2 [21].5.3.2.1.2	The VSS user shall provide the destination address and any of the parameters V32, V33, V34, V35, V36 and Quality of Service parameters (Q2a to Q2d, Q4 and Q5) for which the default values are not desired.	Y	Y	
	Parameter V32 (minimum response delay)			
[1].1.3.14.2.1 [20].5.2.14.1a.3 [21].5.3.2.1.3	Parameter V32 shall be the minimum delay, measured in slot intervals, that a station will provide to a responder in order to ensure that the responder can generate the response before its reserved slot (see note 1).	Y	Y	
	Parameter V33 (maximum response delay)			
[1].1.3.14.2.2 [20].5.2.14.1a.4 [21].5.3.2.1.4	Parameter V33 shall be the maximum delay, measured in slot intervals, that a station will provide to a responder in order to ensure timely delivery in case a retransmission is required.	Y	Y	
	Parameter V34 (source/destination control)			
[1].1.3.14.2.3 [20].5.2.14.1a.5 [21].5.3.2.1.5	Parameter V34 shall control whether the unicast reservation protocol is used to reserve a slot for the destination station to transmit a response to the source (V34 = 0) or for the source station to transmit a response to the destination (V34 = 1).	Y	Y	([50])
[1].1.3.14.2.3 [20].5.2.14.1a.6 [21].5.3.2.1.6	If the broadcast control parameter (V35 = 1), the value of V34 shall be ignored (see note 2).	N	N	
	Parameter V35 (broadcast control)			
[1].1.3.14.2.4 [20].5.2.14.1a.7 [21].5.3.2.1.7	Parameter V35 shall control whether the lowest 24 bits of the destination subfield (d) are included in the reservation.	Y	Y	([51])
[1].1.3.14.2.4 [20].5.2.14.1a.8 [21].5.3.2.1.8	If V35 = 0, then the lowest 24 bits of the destination subfield shall be included and the reservation will be for the station to transmit to or receive from a peer station.	Y	Y	
[1].1.3.14.2.4 [20].5.2.14.1a.9 [21].5.3.2.1.9	Otherwise the lowest 24 bits of the destination subfield shall be omitted, the address type field shall be set to 7 and the reservation will be for the station to make a broadcast transmission.	N	N	
	Parameter V36 (length of reserved block)			
[1].1.3.14.2.5 [20].5.2.14.1a.10 [21].5.3.2.1.10	Parameter V36 shall be the number of reserved slots required for the unicast reservation protocol response.	Y	Y	
NOTE 1: $V32 \times 60/M1$ is the maximum time that a station has to generate a response to the request. NOTE 2: If the destination subfield is omitted (V35 = 1), then the reservation is for the source to broadcast and the value of V34 has no meaning.				

[50] In all simulations, the unicast reservation protocol is used to reserve a slot for the destination station to transmit a response to the source (V34 = 0).

[51] In all simulations, the destination subfield had to be included (V35 = 0), so that the reserved slot was for the peer station to respond (see also above note).

Unicast request reception procedures

Requirement reference		Gnd	Air
[1].1.3.14.3 [20].5.2.14.2.1 [22].5.2.14.2.1	Upon receipt of a burst containing a unicast request reservation, a station shall reserve all of the slots from (1 + ro) through (1 + ro + lg) after the first slot of the received burst for: a) the destination to transmit a response to the source (if sdf = 0 and address type field <> 7); or b) for the source to transmit a response to the destination (if sdf = 1 and address type field <> 7); or c) for the source to make a broadcast transmission (if address type field = 7).	Y	Y

Unicast request transmission procedures

Requirement reference		Gnd	Air	
	Selection of the transmission slot for the unicast request reservation			
[1].1.3.14.4.1 [20].5.2.14.3.1 [21].5.3.2.2.1	If no slot has been reserved for transmission of a unicast reservation, the station shall select a slot using the random access procedures (see [1].1.3.7).	Y	Y	
[1].1.3.14.4.1 [20].5.2.14.3.2 [21].5.3.2.2.2	The transmission slot (t_slot) shall be the slot containing the unicast request reservation transmission.	Y	Y	
	Selection of the reserved slot for the response			
[1].1.3.14.4.2 [20].5.2.14.3.3 [21].5.3.2.2.3	A block of slots of length V36 to be reserved for the response (address type field ≠ 7) or broadcast transmission (address type field = 7) shall be selected using the slot selection procedure specified in [1].1.3.6.2, using VSS user supplied quality of service parameters, and candidate slots in the range V32 to V33 after the transmitted burst.	Y	Y	
[1].1.3.14.4.2 [20].5.2.14.3.4 [21].5.3.2.2.4	The reserved slot (r_slot) shall be the chosen slot or the first slot in the chosen group of slots.	Y	Y	
	Unicast request burst transmission			
[1].1.3.14.4.3.1 [20].5.2.14.3.5 [21].5.3.2.2.5	A station sending a unicast request burst to its peer (V35 = 0) shall include the unicast request reservation field.	Y	Y	
[1].1.3.14.4.3.1 [20].5.2.14.3.6 [21].5.3.2.2.6	It shall set the destination (d) subfield to the destination of the burst, the response offset (ro) subfield to a value of (r_slot - t_slot -1), the length (lg) subfield equal to (V36 - 1), the priority (pr) subfield equal to the priority of the burst to be transmitted as defined by Q1 and the source/destination flag (sdf) to V34.	Y	Y	
[1].1.3.14.4.3.2 [20].5.2.14.3.7 [21].5.3.2.2.7	A station sending a unicast request burst to reserve a slot for a subsequent broadcast (V35 = 1) shall include the unicast request reservation field.	N	N	([52])
[1].1.3.14.4.3.2 [20].5.2.14.3.8 [21].5.3.2.2.8	It shall set the response offset (ro) subfield to a value of (r_slot - t_slot - 1), the length (lg) subfield equal to (V36 - 1), the priority (pr) subfield equal to the priority of the burst to be transmitted as defined by Q1 and the address type field equal to 7.	N	N	
	Retransmission after no response			
[1].1.3.14.4.4 [20].5.2.14.3.9 [21].5.3.2.2.9	In the case of address type subfield ≠ 7 and sdf = 0, if a response is not received by the end of the reserved response slot(s), then the station shall retransmit the unicast burst according to the procedures of [1].1.3.21.	Y	Y	
	Slot selection criteria for unicast request with sdf = 1			
[1].1.3.14.4.5 [20].5.2.14.3.10 [22].5.2.14.3.1	A station applying the slot selection criteria of [1].1.3.6.2.2.1 shall exclude any slot reserved by another station using the unicast request protocol with sdf = 1.	N	N	([53])

[52] The simulated stations never reserve a slot for a subsequent broadcast. See also notes 50 and 51.

[53] The simulated stations never reserve a slot for a subsequent broadcast. See also notes 50 and 51.

NOTE: The use of the unicast request protocol with sdf = 1 allows a station placing the reservation to transmit to a different destination than the destination included in the reservation field. This ability allows a station completing a data transfer with one station to simultaneously start a new data transfer to a different destination. However, since the new destination address is not known by any other station, it is not possible to apply CCI criteria and the slot must be excluded from slot selection.

G.2.15 Information transfer request protocol specification

This protocol is intended for a VSS user which requires a peer VSS user to send a response of length, lg. The protocol also allows the requesting VSS user to place a reservation for an acknowledgement by the requesting VSS user to the response field.

Information transfer request reservation burst format

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

Information transfer request parameters

Requirement reference		Gnd	Air
[1].1.3.15.2 [21].5.3.3.1.1	The information transfer request protocol shall implement the system parameters defined in [1].Table II-1-31.	Y	Y

[1].Table II-1-31: Information transfer request VSS system parameters

Symbol	Parameter name	Minimum	Maximum	Recommended default	Increment
V42	Length of information transfer	1 slot	256 slots	N/A (depends on information to be transmitted)	1 slot
V43	Minimum information transfer delay	2 slot	500 slots	20 slots	1 slot
V44	Maximum information transfer delay	2 slot	2 047 slots	1 000 slots	1 slot
V45	Minimum response delay	2 slot	500 slots	20 slots	1 slot
V46	Maximum response delay	2 slot	2 047 slots	1 000 slots	1 slot

Requirement reference		Gnd	Air
[1].1.3.15.2 [21].5.3.3.1.2	The VSS user shall provide the destination address and any of the parameters V42, V43, V44, V45, V46 and quality of service parameters (Q2a to Q2d and Q4) for which the default values are not desired.	Y	Y
	Parameter V42 (length of information transfer)		
[1].1.3.15.2.1 [21].5.3.3.1.3	Parameter V42 shall be the number of slots required for information transfer.	Y	Y
	Parameter V43 (minimum information transfer delay)		
[1].1.3.15.2.2 [21].5.3.3.1.4	Parameter V43 shall be the minimum delay, measured in slot intervals, that a station will provide to a responder in order to ensure that the responder can generate the required information for transfer before its reserved slots (see note 1).	Y	Y
	Parameter V44 (maximum information transfer delay)		
[1].1.3.15.2.3 [21].5.3.3.1.5	Parameter V44 shall be the maximum delay, measured in slot intervals, that a station will provide to a responder in order to ensure timely delivery in case a retransmission is required.	Y	Y
	Parameter V45 (minimum response delay)		
[1].1.3.15.2.4 [21].5.3.3.1.6	Parameter V45 shall be the minimum delay, measured in slot intervals after the information transfer that the requesting station will require in order to generate an acknowledgement to the information transfer in order to ensure that the requesting station can generate the acknowledgement before its reserved slot (see note 2).	Y	Y
	Parameter V46 (maximum response delay)		
[1].1.3.15.2.5 [21].5.3.3.1.7	Parameter V46 shall be the maximum delay, measured in slot intervals after the information transfer that the requesting station will require in order to ensure timely delivery of the acknowledgement in case a retransmission is required.	Y	Y
NOTE 1: V43 × 60/M1 is the maximum time that a station is provided with to generate a response to the request. NOTE 2: V45 × 60/M1 is the maximum time that a station is provided with to generate an acknowledgement to the information transfer.			

Information transfer request reception procedures

Requirement reference		Gnd	Air
[1].1.3.15.3 [20].5.2.15.2.1 [22].5.2.15.2.1	Upon receipt of a burst containing an information transfer request reservation, a station shall reserve on the specified frequency all of the slots from (1 + ro) through to (1 + ro + lg) after the first slot of the received burst for the destination to transmit one or more information bursts to the source.	Y	Y
[1].1.3.15.3 [20].5.2.15.2.2 [22].5.2.15.2.2	Also, the slot equal to (2 + ro + lg + ao) after the first slot of the received burst shall be reserved for the source to transmit an acknowledgement to the destination on the same frequency as the burst containing the information transfer request reservation.	Y	Y

Information transfer request transmission procedures

Requirement reference		Gnd	Air	
	Selection of the transmission slot for the information transfer request reservation			
[1].1.3.15.4.1 [21].5.3.3.2.1	If no slot has been reserved for transmission of an information transfer request reservation, the station shall select a slot using the random access procedures (see [1].1.3.7).	N	N	([54])
[1].1.3.15.4.1 [21].5.3.3.2.2	The transmission slot (t_slot) shall be the slot containing the information transfer request reservation transmission.	Y	Y	
	Selection of the reserved slots (r_slot) for the response			
[1].1.3.15.4.2 [21].5.3.3.2.3	To reserve a block of slots of length V42 for the response transmission, the slots shall be selected by using: (a) the slot selection procedure specified in [1].1.3.6.2, (b) VSS user-supplied QoS parameters, and (c) candidate slots in the range V43 to V44 after the transmitted burst.	Y	Y	
[1].1.3.15.4.2 [21].5.3.3.2.4	The reserved slot (r_slot) shall be the chosen slot or the first slot in the chosen group of slots.	Y	Y	
	Selection of the reserved slot (a_slot) for the acknowledgement			
[1].1.3.15.4.3 [21].5.3.3.2.5	The acknowledgement slot (a_slot) shall be selected using: (a) the slot selection procedure specified in [1].1.3.6.2, (b) VSS user supplied quality of service parameters, and (c) candidate slots in the range V45 to V46 after the end of the slot or group of slots reserved for the response.	Y	Y	
	Information transfer request burst transmission			
[1].1.3.15.4.4 [21].5.3.3.2.6	A station sending an information transfer request burst to its peer shall include the information transfer request reservation field.	Y	Y	
[1].1.3.15.4.4 [21].5.3.3.2.7	It shall set the parameters to the following values: (a) destination (d) subfield to the destination of the burst; (b) response offset (ro) subfield to a value of (r_slot - t_slot -1); (c) length (lg) subfield equal to (V42-1); (d) frequency (f) subfield set to the channel on which information transfer is required; and (e) acknowledgement offset (ao) subfield set to a value of (a_slot - r_slot - lg - 1).			
	Action after no response			
[1].1.3.15.4.5 [21].5.3.3.2.8	If a response is not received by the reserved information transfer slots, then the station shall inform the VSS user that no response has been received and carry out the actions defined by the VSS user.	Y	Y	
NOTE: If the information transfer protocol is being used as part of DLS long transmission procedure, the defined action is to send a NACK in the slot reserved for the acknowledgement.				

Information transfer request acknowledgement procedures

Requirement reference		Gnd	Air
[1].1.3.15.5 [21].5.3.3.3.1	The acknowledgement shall be on the same frequency as the information transfer reservation burst that was used to reserve a slot for the acknowledgement.	Y	Y

G.2.16 Directed request protocol specification

This protocol is intended for a VSS user which is responding to a plea for slot reservations (rapid network entry), or which requires periodic broadcast responses from a peer VSS user. Both of these scenarios involve reservations calculated and

[54] There is no such operational situation where an information transfer has no reserved slot. This requirement is considered to be an ICAO defect.

declared for use by the peer station. In addition, this protocol allows a VSS user to request that a peer VSS user autonomously transmit at a specified rate.

Not required for targeted simulations, the directed request protocol is not supported.

G.2.17 Block reservation protocols specification

These protocols are intended for a VSS ground station to reserve a block of slots for its own use. The superframe block reservation protocol establishes a series of blocks of slots in which no other station is allowed to place a reservation or to transmit. The second frame block reservation protocol establishes a block at the beginning of each UTC second. Network entry transmissions are also prohibited (see [1].1.3.6.4.3) in both types of blocks. The superframe block reservation protocol provides a facility for re-broadcasting of the block reservation by a mobile.

Not required for targeted simulations, the block reservation protocols are not supported.

G.2.18 Response protocol specification

Response burst format

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

G.2.19 General request protocol specification

This protocol is intended for a VAA user to request that a peer VSS user transmit (either broadcast or unicast request response) certain information.

Not required for targeted simulations, the general request protocol is not supported.

G.2.20 General response protocol specification

Not required for targeted simulations, the general response protocol is not supported.

G.2.21 Retransmission procedures

Requirement reference		Gnd	Air
[1].1.3.21.1 [20].5.2.21.1 [21].5.3.4.1	After transmitting a burst containing a reservation for a peer station (i.e. unicast request reservation, directed request reservation, information transfer request reservation) and not receiving a response by the expected slot, a station shall either retransmit the request or inform the VSS user and LME if Q5num attempts have already been made or if more than Q5wait seconds have elapsed since the VSS user initiated the request.	Y	Y
[20].5.2.21.2 [21].5.3.4.2	The re-transmitting station shall wait for Q5min + *min*(U(x), Q5max) seconds before attempting to retransmit the burst, where: **U(x)** is a uniform random number generated between 0 and x; **x** is defined by Q5mult $\times$ ($Q5exp^{retrans}$) $\times$ M1 /(M1+ 1-u); **u** is the number of occupied slots within the past minute on the channel concerned; **retrans** is the number of times that a burst has been retransmitted (see note).	Y	Y
NOTE: If Q5num = 1, no re-transmission is attempted and hence parameters Q5max, Q5min, Q5mult, Q5exp are not used.			

G.3 DLS sublayer

G.3.1 Services

General

Requirement reference		Gnd	Air	
[1].1.1.2 [21].5.1.1.1.1 [23].5.1.1.1.1	The VDL Link Layer shall provide a reliable point-to-point service using a connection oriented DLS sublayer.	Y	Y	([55])
[1].1.1.2.2 [21].5.1.1.1.2 [23].5.1.1.1.2	The VDL Link Layer shall provide an unacknowledged broadcast service using a connectionless DLS sublayer.	Y	Y	
[1].1.4.1.1.2 [20].5.3.1.1.1 [22].5.3.1.1.1	The DLS shall support broadcast and multicast connectionless communications.	Y	Y	([56])

[55] The ZOCOP protocol is not supported.

[56] Multicast connectionless communications are not supported.

Requirement reference		Gnd	Air	
[1].1.4 [21].5.1.1.1.3 [23].5.1.1.1.3	The DLS shall support communications on a shared communications channel as described in section [1].1.4	Y	Y	
[1].1.4.1.1.1 [21].5.1.1.1.4 [23].5.1.1.1.4	The DLS shall support bit-orientated simplex communications using a Negotiated Setup Connection-Orientated Protocol (NSCOP) between DLE pairs [57].	Y	Y	
[1].1.4.1.1.3 [21].5.1.1.1.5 [23].5.1.1.1.5	The DLS shall provide the following services: a) transmission of user data; b) indication that user data has been sent; c) reception of user data; d) indication that DLS link has been established; e) indication that the DLS link has been broken.	Y	Y	
[1].1.4.1.1.4 [21].5.1.1.1.6 [23].5.1.1.1.6	Stations supporting the [point-to-point] communications functionality provided by the DLS shall simultaneously support at least 8 peer-to-peer links with other stations.	Y	Y	([58])
NOTE 1: It is intended that NSCOP be used for air/ground (A/G) communications. NOTE 2: Any two stations have one DLE pair per frequency.				

Data transfer

Requirement reference		Gnd	Air
[1].1.4.1.2 [21].5.1.1.2.1 [23].5.1.1.2.1	User data packets and LME data shall be transferred in the information fields of INFO, UDATA and CTRL Data Link Protocol Data Units (DLPDUs) which are collectively known as DATA DLPDUs.	Y	Y
[1].1.4.1.2 [20].5.3.1.2.1 [22].5.3.1.2.1 [20].5.3.1.2.2 [21].5.1.1.2.2 [22].5.3.1.2.2 [23].5.1.1.2.2	LME data shall be contained in CTRL and UCTRL frames only.	Y	Y
[1].1.4.1.2 [21].5.1.1.2.3 [23].5.1.1.2.3	The link layer shall process the largest packet size, specified in [1].1.4.3.5 without fragmenting.	Y	Y
[1].1.4.1.2 [21].5.1.1.2.4 [23].5.1.1.2.4	Larger packets shall be fragmented according to the procedures of [1].1.4.4.3.2.	Y	Y
[1].1.4.1.2 [21].5.1.1.2.5 [23].5.1.1.2.5	Only one data link user packet shall be contained in a DATA DLPDU.	Y	Y
NOTE 1: The Frame Mode Subnetwork Dependent Convergence Function (SNDCF) may concatenate multiple packets, but this is presented as a single user data packet to the DLS. NOTE 2: UDATA DLPDUs consist of UINFO DLPDUs for broadcast of user data packets, and UCTRL DLPDUs for broadcast of LME data. UDATA is the broadcast equivalent of DATA and embraces all broadcast-type DLPDUs.			

[57] Because there is no specified application that relies on the ZOCOP protocol, the evaluation of this protocol has not been targeted by this simulation campaign: this protocol is not supported by ACTS/VDL4.

[58] ICAO standard specifies a simultaneous support of 8 peer-to-peer links. ETSI [21].5.1.1.1.6 restricts the usage to 1 link only. ACTS puts no constraints on the number of simultaneous peer-to-peer links, and thus conforms to the ICAO baseline.

DATA DLPDU duplicate suppression and sequencing

Requirement reference		Gnd	Air
[1].1.4.1.3 [21].5.1.1.3.1 [23].5.1.1.3.1	On a point-to-point connection, the receiving DLS sub-layer shall ensure that duplicated DATA DLPDUs are discarded and that all DATA DLPDUs which are part of a fragmented packet are delivered in the same order in which they appear in the packet.	Y	Y
NOTE: To facilitate duplicate suppression, a Toggle bit is included in the DLS DLPDU format.			

Error detection

Requirement reference		Gnd	Air	
[1].1.4.1.4 [21].5.1.1.4.1 [23].5.1.1.4.1	The DLS shall rely on the MAC layer to ensure that DLPDUs corrupted during transmission are detected and discarded.	Y	Y	([59])
NOTE: A 16-bit CRC is provided in the burst format to support this error detection service. The MAC layer will reject corrupted packets.				

Station identification

Requirement reference		Gnd	Air
[1].1.4.1.5 [21].5.1.1.5.1 [23].5.1.1.5.1	A receiving station shall accept unicast DLPDUs addressed to its current station address.	Y	Y
NOTE: Unique source and destination addresses are included in the VDL Mode 4 DLS burst format in order to facilitate station identification. DLPDUs addressed to the current station address are routed to the DLS by the VSS. However, non-unique addressing is possible — with the resultant communications risk minimized through the assurance that any link address is locally unique. The ATN requires a unique address, hence non-unique addressing is not used with the ATN.			

Broadcast addressing

Requirement reference		Gnd	Air	
[1].1.4.1.6 [21].5.1.1.6.1 [23].5.1.1.6.1	A VDL Mode 4 station shall accept broadcast DLPDUs and accept multicast DLPDUs that have been multicast to addresses to which it is listening.	Y	Y	([60])

DLS Priority

Requirement reference		Gnd	Air
[1].1.4.1.7 [21].5.1.1.7.1 [23].5.1.1.7.1	The DLS shall accept an indication of priority of the DATA DLPDUs as defined in [1].Table II-1-11.	Y	Y
NOTE: The DLS service user's selection of priority affects the QoS parameters used in the transfer of the DLS user packet as well as the queuing of the packet.			

[59] See also [1].1.3.1.2 on G.2.1 above.

[60] Multicast connectionless communications are not supported.

DLS Link control DLPDUs

Requirement reference		Gnd	Air
[1].1.4.1.8 [21].5.1.1.8.1 [23].5.1.1.8.1	For the purposes of link control, the DLS shall provide the following DLS DLPDU types: 1 ACK DLPDUs, consisting of INFO_ACK and CTRL_ACK, for the purposes of acknowledgement of DATA DLPDUs and DLS link control DLPDUs respectively. 2 RTS DLPDUs, consisting of CTRL_RTS, INFO_RTS and UDATA_RTS, for the purposes of making reservations for the transfer of DATA DLPDUs. 3 CTS DLPDUs, consisting of CTRL_CTS, INFO_CTS and UDATA_CTS, for purposes of acknowledging RTS DLPDUs and providing slots for subsequent transmission of DATA DLPDUs. 4 Other DLS link control DLPDUs, consisting of SZOM FRMR, FRMR_ACK, DM/DISC and DM/FRMR, for purposes of link initialization, reset and maintenance.	Y	Y

Station address encoding

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

DLS burst formats

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

The requirements that follow are documented because they are not only about encoding and decoding of PDU, but also affect protocol operations.

Requirement reference		Gnd	Air	
[1].1.4.2.3.2.5.1 [21].5.1.2.2.12 [23].5.1.2.2.12	A station receiving a reserved DLPDU from a peer with which it has a link shall reset the link in accordance with the procedures of [1].1.4.4.11.	N	N	([61])
[1].1.4.2.3.2.5.1 [21].5.1.2.2.13 [23].5.1.2.2.13	A station receiving a reserved DLPDU from a peer with which it does not have a link shall either respond with a DM/DISC, DM/FRMR or simply ignore the DLPDU.	N	N	([62])
	Toggle bit			
[1].1.4.2.3.3 [21].5.1.2.2.14 [23].5.1.2.2.14	The T (Toggle) bit shall be alternately set to zero and one on each successful transmission (see note 1).	Y	Y	
[1].1.4.2.3.3 [21].5.1.2.2.15 [23].5.1.2.2.15	At the start of a communication between two stations, or when the link is reset, the toggle bit shall be initiated according to the procedures of [1].1.4.4.3.3.1 for NSCOP communication.	Y	Y	
	More bit			
[1].1.4.2.3.4 [21].5.1.2.2.16 [23].5.1.2.2.16	The M (More) bit shall be set to zero to indicate the end of a user data packet and to one to indicate that this fragment is not the last fragment in a multi-fragment user data packet and that further fragments will be transmitted. (See note 2)	Y	Y	
	Priority subfield			
[1].1.4.2.3.5 [21].5.1.2.2.17 [23].5.1.2.2.17	The priority subfield (pr) shall indicate the priority level of the transmission as defined in [1].1.4.1.7.	Y	Y	
	Length subfield			
[1].1.4.2.3.6 [21].5.1.2.2.18 [23].5.1.2.2.18	The length subfield (lg) shall indicate the length of the DLS burst containing a DATA DLPDU in slots. (See note 3)	Y	Y	
[1].1.4.2.3.6 [21].5.1.2.2.19 [23].5.1.2.2.19	It shall be encoded as one less than the absolute length.	Y	Y	
NOTE 1: The Toggle bit (T) is sufficient to provide duplicate detection and rejection. NOTE 2: The More bit (M) is set to zero if a user data packet is sent as a single fragment or on the last fragment of a fragmented; otherwise, it is set to one. The receiver reassembles a fragmented user data packet on reception before passing it to the user. NOTE 3: In the calculation of length, the size of the reservation protocol (default is response) and the effects of bit stuffing should be taken into account. A length of one ('1') slot would be encoded as 0000 binary and the maximum length of sixteen slots would be encoded as 1111 binary.				

[61] The wording "reserved DLPDU" being unclear and unspecified, there is no feature that supports this requirement.

[62] Same as above.

Requirement reference		Gnd	Air
	Initialize bit		
[1].1.4.2.3.7 [21].5.1.2.2.20 [23].5.1.2.2.20	Prior to sending a CTRL_RTS or upon receipt of a CTRL_RTS with IB (Initialize) Bit set to one the station shall initialize the T_t and T_r state variables and clear the send and receive arrays (see note).	Y	Y
	Compressed combined RTS/INFO DLPDU encoding (type 1)		
[1].1.4.2.3.11 [21].5.1.2.2.21 [23].5.1.2.2.21	A DLS station wishing to send a combined RTS and INFO DLPDU according to the procedures of [1].1.4.4.12 when the priority of the RTS is different to that of the INFO packet shall transmit the compressed combined RTS/INFO (type 1) burst defined in [1].Table II-1-57j with the VSS user supplied QoS and reservation parameters.	Y	Y
[1].1.4.2.3.11 [21].5.1.2.2.22 [23].5.1.2.2.22	The T bit for the RTS shall be the inverse of the INFO bit.	Y	Y
	Compressed combined RTS/INFO DLPDU encoding (type 2)		
[1].1.4.2.3.12 [21].5.1.2.2.23 [23].5.1.2.2.23	A DLS station wishing to send a combined RTS and INFO DLPDU according to the procedures of [1].1.4.4.12, when the priority of the RTS is the same as that of the INFO packet, shall transmit the compressed combined RTS/INFO (type 2) burst defined in [1].Table II-1-57k with the VSS user supplied QoS and reservation parameters.	Y	Y
[1].1.4.2.3.12 [21].5.1.2.2.24 [23].5.1.2.2.24	The T bit for the RTS shall be the inverse of the INFO bit and the priority the same as the INFO priority.	Y	Y

Requirement reference		Gnd	Air
	UDATA DLPDU encoding		
[1].1.4.2.3.10.1 [20].5.3.1.4.1	A DLS station wishing to send a UDATA shall transmit the UDATA bursts defined in [1].Table II-1-57e with the VSS user supplied QoS and reservation parameters.	Y	Y
[1].1.4.2.3.10.1 [20].5.3.1.4.2	The DLS station shall select between [1].Table II-1-57e, [1].Table II-1-57f or [1].Table II-1-57g based on the UDATA ID (udid) of the message as defined by [1].Table II-1-57h.	Y	Y
[1].1.4.2.3.10.2 [20].5.3.1.4.3	A DLS station sending a UCTRL shall set ucd to 0 and encode the appropriate ud field to the value of ucid per [1].Table II-1-57h.	Y	Y
[1].1.4.2.3.10.2 [20].5.3.1.4.4	A DLS station sending a UINFO shall set ucd to 1 and encode the appropriate ud field to the value of uinf per [1].Table II-1-57i.	Y	Y

G.3.2 DLS protocol specification

State Variables

Requirement reference		Gnd	Air
[1].1.4.2.1 [21].5.1.2.1.1 [23].5.1.2.1.1	The DLS shall maintain the state variables defined in [1].Table 1.4.2.1 for each data link between two peer DLEs.	Y	Y
NOTE: If the link is reset for any reason, the DLS will discard any fragments associated with a partially-sent packet.			

[1].Table 1.4.2.1: DLS state variables

State Variable	Usage
T_t	Current value of T bit (0 or 1) for transmitted DLPDUs.
T_r	Value of T bit (0 or 1) for last received DLPDU.
send array	an array storing user data packets and M-bit linked fragments queued for transmission (one per priority level).
receive array	an array storing received M-bit linked fragments queued for concatenation (one per priority level).

G.3.3 DLS system parameters

Requirement reference		Gnd	Air
[1].1.4.3 [20].5.3.2.1 [21].5.1.3.1 [22].5.3.2.1 [23].5.1.3.1	The parameters needed by the DLS sub-layer shall be as listed in [1].Table II-1-58.	Y	Y
[1].1.4.3 [21].5.1.3.2 [23].5.1.3.2	DLS parameters for NSCOP communications shall be determined during the exchange of CTRL DLPDUs, if the default values are not used.	Y	Y

[1].Table II-1-58: DLS system parameters[63]

Symbol	Parameter name	Minimum	Maximum	Default	Increment
ND1	Maximum number of octets in any user data packet	143 octets	2 063 octets	1 511 octets	1 octet
ND2	Maximum length of short DLS transmission	2 octets	496 octets	86 octets	1 octet
ND3	Maximum length of fragment	1 slot	16 slots	5 slots	1 slot
ND4	Maximum length of UDATA burst	23 octets	496 octets	271 octets	1 octet
NOTE:	The value of ND3 should be chosen such that the length of each DLS transmission containing the fragment is less than the maximum length of the DLS transmission defined by ND1 and greater than the maximum length of a short DLS transmission defined by ND2.				

Requirement reference		Gnd	Air
	Parameter ND1 (maximum number of octets of any user data packet)		
[1].1.4.3.3 [21].5.1.3.3 [23].5.1.3.3	The parameter ND1 shall define the maximum number of octets in any user data packet that a DLS may accept from the data link user or from a peer station.	Y	Y
[1].1.4.3.3 [21].5.1.3.4 [23].5.1.3.4	A station receiving a user data packet from a peer station greater in length than ND1 shall discard the packet and reset the link in accordance with the procedures of [1].1.4.4.11.	Y	Y
[1].1.4.3.3 [21].5.1.3.5 [23].5.1.3.5	A station receiving a user data packet from a data link user greater in length than ND1 shall discard the packet (see note 1).	Y	Y
	Parameter ND2 (maximum length of a short DLS transmission)		
[1].1.4.3.4 [21].5.1.3.6 [23].5.1.3.6	The parameter ND2 shall define the maximum size in octets of a short DLS transmission including flags and reservation data that shall be sent using the short transmission procedures defined in [1].1.4.4.5.	Y	Y
[1].1.4.3.4 [21].5.1.3.7 [23].5.1.3.7	A burst occupying x slots shall contain up to 23 + (((x-1)×63)/2) octets of data including reservation data, CRC and flags (see note 2).	Y	Y
	Parameter ND3 (maximum length of fragment)		
[1].1.4.3.5 [21].5.1.3.8 [23].5.1.3.8	The parameter ND3 shall define the maximum size in slots of a DLS burst.	Y	Y
	Parameter ND4 (maximum length of UDATA burst)		
[1].1.4.3.6 [20].5.3.2.1.1 [22].5.3.2.1.1	The parameter ND4 shall define the maximum size in octets of a UDATA burst.	Y	Y

[63] The ZOCOP protocol being not supported, TD1 and TD2 parameters have intentionally been removed from the table.

NOTE 1:	The maximum size of a user data packet for broadcast is set by parameter ND4.
NOTE 2:	A slot can contain 32 octets of data but the last slot in a sequence should only contain 24 octets to allow for propagation guard time. Allowing an average of one octet for every two slots for bit stuffing, one slot could contain 23 octets of data (including flags and reservation blocks); two slots could contain 54 octets; three slots could contain 86 octets; and so forth.

G.3.4 DLS procedures

Broadcast

Requirement reference		Gnd	Air
[1].1.4.4.1 [20].5.3.3.1.1 [22].5.3.3.1.1	Only UDATA DLPDUs shall be broadcast.	Y	Y
	Action on receipt of UDATA DLPDU		
[1].1.4.4.5.4 [20].5.3.3.1.2 [22].5.3.3.1.2	A station receiving a UDATA DLPDU shall forward the contents of the information field to the DLS user and take no further action.	Y	Y
NOTE: Either the mobile or ground station may send user data packets at any time and is considered peers with respect to management of the link.			

Setting of re-transmission parameter

Requirement reference		Gnd	Air
[1].1.4.4.2 [21].5.1.4.1.1 [23].5.1.4.1.1	For all DLS bursts containing CTRL, INFO, CTRL_RTS, INFO_RTS and UCTRL_RTS DLPDUs, the quality of service parameters Q5min, Q5max, Q5mult, Q5exp and Q5num shall be set as defined in [1].Table II-1-59.	Y	Y
NOTE: Re-transmission of DLS DLPDUs may be handled in the VSS or DLS.			

[1].Table II-1-59: DLS Re-transmission parameters

Symbol	Parameter name		Default
Q5min	VSS retransmission parameters	Minimum	1 s
Q5max		Maximum	15 s
Q5mult		Multiplier	1,45
Q5exp		Exponent	1,7
Q5num		number of attempts	4
Q5wait		maximum time to wait for a reply	20 s

Selection of user data packet for transmission

Requirement reference		Gnd	Air
	User data packet priority		
[1].1.4.4.3.1.1 [21].5.1.4.2.1 [23].5.1.4.2.1	A sending station shall maintain a prioritized queue of user data packets for transmission.	Y	Y
[1].1.4.4.3.1.2 [21].5.1.4.2.2 [23].5.1.4.2.2	When determining which user data packet to transmit, the highest priority user data packet shall be sent first.	Y	Y
[1].1.4.4.3.1.3 [21].5.1.4.2.3 [23].5.1.4.2.3	The DLS DLPDUs CTRL and CTRL_RTS shall be classified as network management messages and given the highest priority.	Y	Y
[1].1.4.4.3.1.4 [21].5.1.4.2.4 [23].5.1.4.2.4	The DLS DLPDUs INFO_RTS, and UDATA_RTS shall be assigned the same priority as the DATA DLPDU with which they are associated. (See note)	Y	Y
	User data packet fragmentation		
	Determination of single or multiple fragment transmission		
[1].1.4.4.3.2.1.1 [21].5.1.4.2.5 [23].5.1.4.2.5	If the length of the DLS burst containing a CTRL or INFO DLPDU is greater than ND2 octets, the sending station shall fragment the user data packet into one or more fragments of maximum size ND3, and format it according to the procedures of [1].1.4.4.3.2.3.	Y	Y
[1].1.4.4.3.2.1.1 [21].5.1.4.2.6 [23].5.1.4.2.6	Otherwise the user data packet shall be sent as a single fragment formatted according to the procedures of [1].1.4.4.3.2.2.	Y	Y
[1].1.4.4.3.2.1.2 [21].5.1.4.2.7 [23].5.1.4.2.7	The fragmentation of a user data packet shall take account of whether the station is combining a CTRL or INFO DLPDU with another DLS DLPDU in accordance with the procedures of [1].1.4.4.12.3.	Y	Y
	Single fragment user data packet transmission		
[1].1.4.4.3.2.2 [21].5.1.4.2.8 [23].5.1.4.2.8	A single fragment user data packet shall be transferred as a CTRL or INFO DLPDU.	Y	Y
[1].1.4.4.3.2.2 [21].5.1.4.2.9 [23].5.1.4.2.9	The M bit shall be set to zero.	Y	Y
[1].1.4.4.3.2.2 [21].5.1.4.2.10 [23].5.1.4.2.10	For an INFO DLPDU, the pr bits shall indicate the priority of the DLPDU.	Y	Y
	Multiple fragment user data packet transmission		
[1].1.4.4.3.2.3 [21].5.1.4.2.11 [23].5.1.4.2.11	A multiple fragment user data packet shall be transferred as a series of CTRL or INFO DLPDUs using the long transmission procedures defined in [1].1.4.4.6.	Y	Y
[1].1.4.4.3.2.3 [21].5.1.4.2.12 [23].5.1.4.2.12	The M bit shall be set to 1 for all fragments except the last fragment.	Y	Y
[1].1.4.4.3.2.3 [21].5.1.4.2.13 [23].5.1.4.2.13	The M bit shall be set to 0 for the last fragment.	Y	Y
[1].1.4.4.3.2.3 [21].5.1.4.2.14 [23].5.1.4.2.14	For INFO DLPDUs, the pr bits shall indicate the priority of the DLPDU.	Y	Y
NOTE: All other DLS DLPDU types will be sent in pre-reserved slots (FRMR, DM/FRMR and DM/DISC) or will take the priority of the DATA packet with which they are combined (SZOM). Hence priority is not an issue.			

Requirement reference		Gnd	Air	
	Setting of T bit			
	T bit initialization for NSCOP communication			
[1].1.4.4.3.3.1 [21].5.1.4.2.15 [23].5.1.4.2.15	When there is no established link (or link in the process of being established) between a mobile DLE and a ground DLE and the LME of either station requests the transmission of a CTRL user data packet, the sending DLE shall send the CTRL DLPDU using the long transmission procedures (see [1].1.4.4.6). (See notes 1 and 2)	Y	Y	
[1].1.4.4.3.3.1 [21].5.1.4.2.16 [23].5.1.4.2.16	In the CTRL_RTS, it shall set the IB bit to 1, the T bit to 0, and follow the procedures of [1].1.4.2.3.7.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.17 [23].5.1.4.2.17	On receipt of a CTRL_RTS DLPDU with IB = 1, the receiving DLE shall follow the procedures of [1].1.4.2.3.7.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.18 [23].5.1.4.2.18	The sender and receiver shall consider the link initialized.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.19 [23].5.1.4.2.19	The receiver shall immediately terminate any INFO transfers in progress.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.20 [23].5.1.4.2.20	Any partially received CTRL DLPDUs shall be discarded.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.21 [23].5.1.4.2.21	If any CTRL fragments had already been acknowledged, then the remainder of the CTRL DLPDU shall be abandoned.	Y	Y	
[1].1.4.4.3.3.1.1 [21].5.1.4.2.22 [23].5.1.4.2.22	However, if no CTRL_ACK had been received for a CTRL DLPDU, then its transfer shall continue unaffected.	Y	Y	
[1].1.4.4.3.3.1.2 [21].5.1.4.2.23 [23].5.1.4.2.23	The DLE shall consider the link connected upon direction from the LME. (See note 3)	Y	Y	
[1].1.4.4.3.3.1.2 [21].5.1.4.2.24 [23].5.1.4.2.24	INFO, INFO_RTS, INFO_ACK and INFO_CTS DLPDUs shall only be sent on links that are connected.	Y	Y	
[1].1.4.4.3.3.1.2 [21].5.1.4.2.25 [23].5.1.4.2.25	Although a DLE may receive INFO DLPDUs (and generate INFO_ACKs), it shall not transmit INFO DLPDUs until it receives a CTRL_ACK to its CTRL (M = 0).	Y	Y	
[1].1.4.4.3.3.1.3 [21].5.1.4.2.26 [23].5.1.4.2.26	On receipt of a CTRL_RTS, in a DLS burst addressed to it for which IB is equal to 1 and for which the T bit is equal to 1 a station shall send a DM/FRMR.	Y	Y	
[1].1.4.4.3.3.1.3 [21].5.1.4.2.27 [23].5.1.4.2.27	If a DLE with unininitialized state variables receives a CTRL_RTS DLPDU with IB equal to 0, then it shall respond with a DM/FRMR.	Y	Y	
[1].1.4.4.3.3.1.4 [21].5.1.4.2.28	If a DLE receives an SZOM from a peer DLE, it shall respond with a DM/FRMR.	N	N	([64])

[64] ZOCOP communications are not supported.

Requirement reference		Gnd	Air
[23].5.1.4.2.28			
	Transfer after initialization		
[1].1.4.4.3.3.3 [21].5.1.4.2.29 [23].5.1.4.2.29	When the T bit has been initialized, the sending station shall set the T bit for transmitted DLPDUs to the value of T_t.	Y	Y
NOTE 1: The DLE to which the mobile sent the CTRL_CMD may not be the DLE which responds with the CTRL_RSP. NOTE 2: INFO DLPDUs and partially sent or received CTRL DLPDUs are abandoned mid-transfer on the presumption that the peer station has restarted (there is no other legitimate reason for the IB = 1). NOTE 3: If the receving LME indicates to the receiving DLE that the link is estabished after the receiving DLE's transmission of the CTRL_ACK, then the receiving DLE will not respond with a DM/FRMR to the INFO_RTS or INFO that it receives.			

Selection of transmission procedures

Requirement reference		Gnd	Air
[1].1.4.4.4 [21].5.1.4.3.1 [23].5.1.4.3.1	After a packet has been selected for transmission according to the procedures of [1].1.4.4.3 the sending station shall calculate the total length in octets of the DLS burst required to contain the DLPDU queued for transmission using the short transmission procedures defined in [1].1.4.4.5.	Y	Y
[1].1.4.4.4 [21].5.1.4.3.2 [23].5.1.4.3.2	The total length shall include the length of any reservation fields contained within the DLS burst, together with any flags.	Y	Y
[1].1.4.4.4 [21].5.1.4.3.3 [23].5.1.4.3.3	The calculation of the length of the DLS burst shall take account of whether the station will combine a DATA DLPDU with another DLS DLPDU in accordance with the procedures of [1].1.4.4.12.3.	Y	Y
[1].1.4.4.4 [21].5.1.4.3.4 [23].5.1.4.3.4	If the total length is less than or equal to ND2, then the station shall use short transmission procedures ([1].1.4.4.5) to transmit the queued data.	Y	Y
[1].1.4.4.4 [21].5.1.4.3.5 [23].5.1.4.3.5	Otherwise, the station shall use the long transmission procedures ([1].1.4.4.6).	Y	Y
[1].1.4.4.4 [21].5.1.4.3.6 [23].5.1.4.3.6	The M bit shall be set to zero (M=0) for a short transmission.	Y	Y
	Recommendation		
[1].1.4.4.4.1 [21].5.1.4.3.7 [23].5.1.4.3.7	If there are other DLPDUs queued for transmission, then the station should also include an RTS in accordance to [1].1.4.4.12.3.	Y	Y

Short transmission procedures

Requirement reference		Gnd	Air
	Transmission of DATA DLPDU		
[1].1.4.4.5.1.1 [21].5.1.4.4.1 [23].5.1.4.4.1	After the selection of a short transmission procedure, the sending station shall transmit a DLS burst containing the DATA DLPDU queued for transmission with QoS parameters as defined in [1].Table II-1-60 using the random access procedures.	Y	Y
[1].1.4.4.5.1.1 [21].5.1.4.4.2 [23].5.1.4.4.2	For CTRL and INFO DLPDUs, the T bit shall be set to T_t.	Y	Y
[1].1.4.4.5.1.2 [21].5.1.4.4.3 [23].5.1.4.4.3	A burst containing a CTRL or INFO DLPDU shall contain a unicast request reservation field for the acknowledgement with the parameters in [1].Table II-1-60. (See notes 1 and 2)	Y	Y
	Acknowledgement of DATA DLPDU		
	Established link with sender		
[1].1.4.4.5.2.1 [21].5.1.4.4.4 [23].5.1.4.4.4	If a station receiving a CTRL or INFO DLPDU has an established link with the sender it shall transmit a DLS burst containing an ACK DLPDU in the slot reserved by the unicast request reservation field contained in the DATA DLPDU transmission (see note 3):	Y	Y
[1].1.4.4.5.2.1 [21].5.1.4.4.5 [23].5.1.4.4.5	a) A CTRL_ACK DLPDU shall be sent in response to a CTRL DLPDU and an INFO_ACK DLPDU sent in response to an INFO DLPDU.	Y	Y
[1].1.4.4.5.2.1 [21].5.1.4.4.6 [23].5.1.4.4.6	b) The T bit shall be set to the value of the T bit in the received DATA DLPDU.	Y	Y
	Non-receipt of acknowledgement		
[1].1.4.4.5.3 [21].5.1.4.4.7 [23].5.1.4.4.7	If an acknowledgement to a CTRL or INFO DLPDU is not received from the receiving station, the sending station shall retransmit the DLS burst containing the CTRL or INFO DLPDU and a unicast request reservation field according to the procedures of [1].1.3.21.	Y	Y
NOTE 1: The priority field in the unicast reservation field is set equal to the priority setting in the INFO DLPDU as specified in [1].Table II-1-60. NOTE 2: If the responder VSS sub-layer has not received a response from the VSS user in the scheduled reservation, it can send: a) a GENERAL FAILURE (see [1].1.3.20) with error type (err) 7E hex or FE hex; and b) a unicast request reservation according to the procedures of [1].1.3.19.2. NOTE 3: See [1].1.4.4.12 for an example of when the response reservation type is not used.			

[1].Table II-1-60: Short transmission INFO DLPDU parameters

Symbol	Parameter name	Default
V32	Minimum response delay	(54 ms) × M1/60 slots
V33	Maximum response delay	(5 s) × M1/60 slots
V34	Source/destination control	0
V35	Broadcast control	0
V36	Length of reserved block	1 slot
Q1	Priority	Priority of INFO DLPDU
Q2a	Slot selection range constraint for level 1	150 NMI
Q2b	Slot selection range constraint for level 2	150 NMI
Q2c	Slot selection range constraint for level 3	0 NMI
Q2d	Slot selection range constraint for level 4	300 NMI
Q3	Replace queued data	FALSE
Q4	Number of available slots	3

Long transmission procedures

Requirement reference		Gnd	Air
	Transmission of Request to Send (RTS)		
[1].1.4.4.6.1 [21].5.1.4.5.1 [23].5.1.4.5.1	After the selection of a long transmission procedure, the sending station shall transmit a DLS burst containing an RTS DLPDU to the receiving station in the transmit queue with QoS parameters as defined in [1].Table II-1-61.	Y	Y
[1].1.4.4.6.1 [21].5.1.4.5.2 [23].5.1.4.5.2	When using the long transmission procedure: a) A station shall send a CTRL_RTS, INFO_RTS or UDATA_RTS DLPDU if a CTRL, INFO or UDATA DLPDU respectively is to be transmitted.	Y	Y
[1].1.4.4.6.1 [21].5.1.4.5.3 [23].5.1.4.5.3	b) The pr subfield shall indicate the priority of the INFO_RTS and UDATA_RTS DLPDUs to be transmitted (see [1].1.4.1.7).	Y	Y
[1].1.4.4.6.1 [21].5.1.4.5.4 [23].5.1.4.5.4	c) The length subfield shall indicate the length of the DLS burst required to contain the DATA DLPDU (see [1].1.4.2.3.6).	Y	Y
[1].1.4.4.6.1 [21].5.1.4.5.5 [23].5.1.4.5.5	d) For CTRL_RTS and INFO_RTS DLPDUs, the T bit shall be set to T_t.	Y	Y
[1].1.4.4.6.1 [21].5.1.4.5.6 [23].5.1.4.5.6	Each burst shall contain a unicast request reservation field with the parameters set as defined in [1].Table II-1-61.	Y	Y
NOTE 1: The ground may use the priority (pr) subfield to manage the link resource during congestion. NOTE 2: Transfer of broadcast data using the long transmission procedures involves directing the UDATA_RTS at a specific station, receiving a set of slots from that station via the UDATA_CTS, and then broadcasting the UDATA in the reserved slots. NOTE 3: The priority field in the unicast request reservation field is set equal to the priority setting in the INFO DLPU as specified in [1].Table II-1-61.			

[1].Table II-1-61: Long transmission RTS DLPDU parameters

Symbol	Parameter name	Default
V32	Minimum response delay	(54 ms) × M1/60 slots
V33	Maximum response delay	(5 s) × M1/60 slots
V34	Source/destination control	0
V35	Broadcast control	0
V36	Length of reserved block	1 slot
Q1	Priority	Priority of RTS
Q2a	Slot selection range constraint for level 1	150 NMI
Q2b	Slot selection range constraint for level 2	150 NMI
Q2c	Slot selection range constraint for level 3	0 NMI
Q2d	Slot selection range constraint for level 4	300 NMI
Q3	Replace queued data	FALSE
Q4	Number of available slots	3

Requirement reference		Gnd	Air
	Response to Request to Send (RTS)		
	Response if a DATA DLPDU has not previously been received		
[1].1.4.4.6.3.1.1 [21].5.1.4.5.7 [23].5.1.4.5.7	If the responder has an established link with the sender and the received DLPDU is a UDATA_RTS or if the T bit within the CTRL_RTS or INFO_RTS DLPDU is not equal to T_r, then the receiving station shall transmit a CTS DLPDU in a DLS burst in the slot reserved by the RTS DLPDU.	Y	Y
[1].1.4.4.6.3.1.2 [21].5.1.4.5.8 [23].5.1.4.5.8	A CTRL_CTS, INFO_CTS or UDATA_CTS DLPDU shall be sent in response to a CTRL_RTS, INFO_RTS or UDATA_RTS DLPDU respectively.	Y	Y
[1].1.4.4.6.3.1.3 [21].5.1.4.5.9 [23].5.1.4.5.9	For CTRL_CTS and INFO_CTS DLPDUs, the burst shall contain an information transfer request reservation field and be transmitted with the parameters in [1].Table II-1-63, indicating the number of slots reserved for transfer of the DATA DLPDU.	Y	Y
[1].1.4.4.6.3.1.4 [21].5.1.4.5.10 [23].5.1.4.5.10	For a UDATA_CTS DLPDU, the burst shall contain a unicast request reservation field and be transmitted with the parameters in [1].Table II-1-61, indicating the number of slots reserved for transfer of the DATA DLPDU.	Y	Y
	Response if a DATA DLPDU has previously been received		
[1].1.4.4.6.3.2 [21].5.1.4.5.11 [23].5.1.4.5.11	If the responder has an established link with the sender and if the T bit within the CTRL_RTS or INFO_RTS DLPDU is equal to T_r, then the receiving station shall transmit an ACK DLPDU in the slot reserved by the RTS.	Y	Y
[1].1.4.4.6.3.2 [21].5.1.4.5.12 [23].5.1.4.5.12	a) A CTRL_ACK or INFO_ACK DLPDU shall be sent in response to a CTRL_RTS or INFO_RTS DLPDU respectively.	Y	Y
[1].1.4.4.6.3.2 [21].5.1.4.5.13 [23].5.1.4.5.13	b) The T bit shall be set to the value of the T bit in the received DATA DLPDU.	Y	Y
[1].1.4.4.6.3.2 [21].5.1.4.5.14 [23].5.1.4.5.14	The DLS burst containing the ACK DLPDU shall contain a response reservation type except as determined by the procedures of [1].1.4.4.12.	Y	Y
	Channel too busy		
[1].1.4.4.6.3.3 [21].5.1.4.5.15 [23].5.1.4.5.15	If the channel is too busy (either the receiving station cannot find a sufficiently large series of contiguous slots or the priority is too low for the channel utilization), then the receiving station shall transmit either: a GENERAL CONFIRM including a unicast reservation with V34 = 1 indicating when the responder will transmit an information transfer request in response to the RTS; or, a GENERAL FAILURE (see [1].1.3.20) with error type = 01 hex.	Y	Y
NOTE: If the responder sends a GENERAL FAILURE (see [1].1.3.20), the sender can re-transmit the RTS after the time out defined by the back-off delay or in the slot reserved by the destination.			

Table [21].5.12: CTS DLPDU parameters

Symbol	Parameter name	Default
V42	Length of information transfer	Sufficient to include requested INFO DLPDUs
V43	Minimum information transfer delay	(54 ms) × M1/60 slots
V44	Maximum information transfer delay	(5 s) × M1/60 slots
V45	Minimum response delay	(54 ms) × M1/60 slots
V46	Maximum response delay	(5 s) × M1/ slots
Q1	Priority	Priority of RTS
Q2a	Slot selection range constraint for level 1	150 NMI
Q2b	Slot selection range constraint for level 2	150 NMI
Q2c	Slot selection range constraint for level 3	0 NMI
Q2d	Slot selection range constraint for level 4	300 NMI
Q3	Replace queued data	FALSE
Q4	Number of available slots	3

Requirement reference		Gnd	Air
	Response to Clear to Send (CTS)		
	Transmission of DATA DLPDU		
[1].1.4.4.6.4.1.1 [21].5.1.4.5.16 [23].5.1.4.5.16	On receipt of a CTRL_CTS or INFO_CTS DLPDU in a DLS burst addressed to it and with an information transfer request reservation field a station shall transmit the requested DATA DLPDU in the allocated reservation with the T bit set to T_t.	Y	Y
[1].1.4.4.6.4.1.1 [21].5.1.4.5.17 [23].5.1.4.5.17	The DLS burst containing the DATA DLPDU shall contain a response reservation type.	Y	Y
[1].1.4.4.6.4.1.2 [21].5.1.4.5.18 [23].5.1.4.5.18	On receipt of a UDATA_CTS DLPDU in a DLS burst addressed to it with a unicast request reservation field a station shall transmit the requested UDATA DLPDU in the allocated reservation.	Y	Y
	Response if no information to transmit		
[1].1.4.4.6.4.2 [21].5.1.4.5.19 [23].5.1.4.5.19	If upon receipt of a CTS the station has nothing to transmit (e.g. after a reset), it shall transmit one of the following: a) an FRMR if the link is connected; b) a DM/DISC if the link is disconnected; c) a DM/FRMR if the link is in the process of connecting.	Y	Y
	Recommendation		
[1].1.4.4.6.4.3 [21].5.1.4.5.20 [23].5.1.4.5.20	If the station has not transmitted an INFO DLPDU and a higher priority user data packet arrived after the RTS had been transmitted, the station should transmit as much of the highest priority packets as will fit in the current reservation with the same value for T as contained in the RTS.	N	N
	Acknowledging the data		
	DATA DLPDU received		
[1].1.4.4.6.5.1 [21].5.1.4.5.21 [23].5.1.4.5.21	A receiving station which transmitted a CTRL_CTS or INFO_CTS DLPDU in a DLS burst containing an information transfer request reservation field (and consequently has a reservation for an acknowledgement) and which has received the DATA DLPDU with a T bit not equal to T_r, shall follow the procedures of [1].1.4.4.5.2.1.	Y	Y
	Response if DATA DLPDU not received		
[1].1.4.4.6.5.2.1 [21].5.1.4.5.22 [23].5.1.4.5.22	A receiving station which transmitted a CTRL_CTS or INFO_CTS DLPDU in a DLS burst containing an information transfer request reservation field (and consequently has a reservation for an acknowledgement) and which has not received the CTRL or INFO DLPDU with a T bit not equal to T_r, shall transmit in the slot reserved for an acknowledgement an ACK DLPDU in a DLS burst.	N (*)	N (*)
[1].1.4.4.6.5.2.1 [21].5.1.4.5.23 [23].5.1.4.5.23	a) A CTRL_ACK or INFO_ACK DLPDU shall be sent in response to a CTRL or INFO DLPDU respectively.	N (*)	N (*)
[1].1.4.4.6.5.2.1 [21].5.1.4.5.24 [23].5.1.4.5.24	b) The T bit shall be set to the inverse of the value of the T bit in the last received RTS DLPDU. (See note)	N (*)	N (*)
[1].1.4.4.6.5.2.2 [21].5.1.4.5.25 [23].5.1.4.5.25	The DLS burst containing the ACK DLPDU shall contain a response reservation type.	Y	Y
NOTE: The use of the Toggle bit (T) not equal to T_r indicates a negative acknowledgement (NACK).			

(*) Requirement [1].1.4.4.6.5.2.1 conflicts with [1].1.3.21.1. For protocol efficiency reasons, the later requirement shall prevail (restart transmission process as soon as possible). ACTS/VDL4 considers [1].1.4.4.6.5.2.1 an ICAO defect.

DLS not supported

Requirement reference		Gnd	Air	
[1].1.4.4.7 [20].5.3.3.2.1 [22].5.3.3.2.1	If the responder to a DLS DLPDU other than a UDATA DLPDU does not support the DLS, then it shall transmit a GENERAL FAILURE (see [1].1.3.20) with an error type of 80 hex in the slot reserved by the unicast request reservation field contained in the data DLPDU transmission.	N	N	([65])
NOTE: The response upon receipt of a GENERAL FAILURE, described in [1].1.3.20.1, is to not transmit another DLS burst to the ending station for the duration of the backoff timer.				

No link with sender

Requirement reference		Gnd	Air
[1].1.4.4.8 [21].5.1.4.6.1 [23].5.1.4.6.1	If the responder to any DLPDU other than a CTRL_RTS DLPDU with IB equal to 1 neither has nor is attempting to establish a link with the sender, the responder shall send a DLS burst containing a DM/DISC DLPDU in the slot reserved by the unicast or information transfer request reservation field contained in the data DLPDU transmission.	Y	Y
[1].1.4.4.8 [21].5.1.4.6.2 [23].5.1.4.6.2	If the responder is trying to establish a link with the sender, then it shall respond with a DM/FRMR to any DLPDU other than a CTRL-related DLPDU.	Y	Y
NOTE: Per [1].1.4.4.3.3.1, an NSCOP link is considered established when a DLE sends or receives the last fragment of a CTRL_RSP. Consequently, a DLE may be retransmitting the last fragment of a CTRL_RSP whilst it is acknowledging INFO DLPDUs.			

[65] No such cases ever happen in simulations.

User data packet reception

Requirement reference		Gnd	Air
	Receipt and forwarding of received DATA DLPDUs		
[1].1.4.4.9.1.1 [21].5.1.4.7.1 [23].5.1.4.7.1	When a CTRL or INFO DLPDU is received without errors from another station, the value of the T bit shall be inspected and recorded.	Y	Y
[1].1.4.4.9.1.1 [21].5.1.4.7.2 [23].5.1.4.7.2	If the value of the T bit is not equal to T_r, then the user data packet or user data packet fragment shall be accepted and T_r set to the value of the T bit in the received INFO or CTRL DLPDU.	Y	Y
[1].1.4.4.9.1.1 [21].5.1.4.7.3 [23].5.1.4.7.3	Otherwise, the received user data packet or user data packet fragment shall be discarded as a duplicate.	Y	Y
[1].1.4.4.9.1.2 [20].5.3.3.3.1 [22].5.3.3.3.1	When a UDATA DLPDU is received without errors from another station, it shall be passed to the service user as a single incoming user data packet.	Y	Y
[1].1.4.4.9.1.2 [20].5.3.3.3.2 [22].5.3.3.3.2	Otherwise it shall be discarded.	Y	Y
	Concatenation of multiple fragment user data packets		
[1].1.4.4.9.2.1 [21].5.1.4.7.4 [23].5.1.4.7.4	If any preceding user data packet fragments have been received with, in the case of an INFO DLPDU, the same value of pr subfield and with the M bit set to one, then the user data part of the received DATA DLPDU shall be concatenated to the end of the user data packet fragments.	Y	Y
[1].1.4.4.9.2.2 [21].5.1.4.7.5 [23].5.1.4.7.5	If the M bit is set to zero on the received DATA DLPDU, then the user data part of the received DATA DLPDU, including any user data packet fragments received earlier and with which it has been concatenated, shall be passed to the service user as a single incoming user data packet.	Y	Y
	Unacknowledged DLPDUs		
[1].1.4.4.9.3 [20].5.3.3.3.3 [21].5.1.4.7.6 [22].5.3.3.3.3 [23].5.1.4.7.6	UDATA, DM/DISC, DM/FRMR and all ACK DLPDUs shall be unacknowledged.	Y	Y

Receipt of ACK DLPDU

Requirement reference		Gnd	Air
	Receipt of an expected ACK DLPDU		
[1].1.4.4.10.1.1 [21].5.1.4.8.1 [23].5.1.4.8.1	When an ACK DLPDU is received without errors from another station and there was an outstanding DATA DLPDU to be acknowledged, the value of the T bit shall be inspected and the following operations performed.	Y	Y
[1].1.4.4.10.1.2 [21].5.1.4.8.2 [23].5.1.4.8.2	If T is equal to T_t, then the DATA DLPDU shall be assumed successfully received and the value of T_t set to the inverse of the current value of T_t.	Y	Y
[1].1.4.4.10.1.3 [21].5.1.4.8.3 [23].5.1.4.8.3	If the ACK DLPDU is not received by the expected reserved slot, then the sending station shall re-send the DATA DLPDU using the short or long transmission procedures as determined by the procedures of [1].1.4.4.4 (See note 1).	Y	Y
[1].1.4.4.10.1.4 [21].5.1.4.8.4 [23].5.1.4.8.4	When a DATA DLPDU has been successfully received, the highest priority fragment (either the next fragment of the current user data packet or the first fragment/complete DLPDU of the next user data packet) in the send queue, if any, shall be selected for transmission using the procedures of [1].1.4.4.3 (See note 2)	Y	Y
	Receipt of an unexpected ACK DLPDU		
[1].1.4.4.10.2 [21].5.1.4.8.5 [23].5.1.4.8.5	When an ACK DLPDU is received without errors from another station and there was no outstanding DATA DLPDUs to be acknowledged, the value of the T bit shall be inspected and the following operations performed.	Y	Y
[1].1.4.4.10.2 [21].5.1.4.8.6 [23].5.1.4.8.6	If T is equal to T_t then the link shall be reset as per [1].1.4.4.11.	Y	Y
[1].1.4.4.10.2 [21].5.1.4.8.7 [23].5.1.4.8.7	If T is not equal to T_t then the ACK shall be ignored.	Y	Y
NOTE 1: Retransmission is based on the expected receipt time and not on the receipt of a NACK. NOTE 2: The selection of highest priority allows the station to pre-empt a lower priority transfer (e.g. more bit (M) linked fragments) with a higher priority user data packet or set of fragments.			

Link reset

Requirement reference		Gnd	Air
	Link reset during link setup		
[1].1.4.4.11.1 [21].5.1.4.9.1 [23].5.1.4.9.1	The sending station shall disconnect the link by sending a DM/FRMR DLPDU, which is transmitted in the reservation placed for the response.	Y	Y
[1].1.4.4.11.1 [21].5.1.4.9.2 [23].5.1.4.9.2	Upon receipt of a DM/FRMR DLPDU, the receiving station shall disconnect the link.	Y	Y
	Link reset of an established link		
[1].1.4.4.11.2.1 [21].5.1.4.9.3 [23].5.1.4.9.3	The sending station shall reset the link by sending a FRMR DLPDU in a DLS burst placing a unicast reservation for the response.	Y	Y
[1].1.4.4.11.2.1 [21].5.1.4.9.4 [23].5.1.4.9.4	The sending station shall also discard all outstanding user data packets in the SEND and RECEIVE array.	Y	Y
[1].1.4.4.11.2.1	The receiving station shall clear the state variables and discard all outstanding user data packets in the SEND and RECEIVE array.	Y	Y
[1].1.4.4.11.2.1 [21].5.1.4.9.5 [23].5.1.4.9.5	If a FRMR_ACK is not received in the reserved slot, the FRMR shall be sent again using the re-transmission procedures.	Y	Y
[1].1.4.4.11.2.1 [21].5.1.4.9.6 [23].5.1.4.9.6	Only when a FRMR_ACK has been received shall the station attempt to re-send data to the receiving station using the procedures of [1].1.4.4.3.3.	Y	Y
[1].1.4.4.11.2.1 [21].5.1.4.9.7 [23].5.1.4.9.7	If the sending station receives an INFO or RTS DLPDU from the peer whilst waiting for a FRMR_ACK, it shall send an FRMR in response.	Y	Y
[1].1.4.4.11.2.1 [21].5.1.4.9.8 [23].5.1.4.9.8	Upon receipt of an unsolicited FRMR_ACK, a DLE shall respond with an FRMR.	Y	Y
[1].1.4.4.11.2.2 [21].5.1.4.9.9 [23].5.1.4.9.9	On receipt of a FRMR DLPDU, the receiving station shall discard any outstanding fragments in the receive array and transmit a FRMR_ACK DLPDU in a DLS burst in the reserved slot.	Y	Y

Linking DLS DLPDU transmissions

Requirement reference		Gnd	Air	
[1].1.4.4.12 [21].5.1.4.10.1 [23].5.1.4.10.1	An implementation of the DLS shall be capable of providing a combined DLPDU response even if the station does not initiate the use of combined DLPDUs.	Y	Y	
	Recommendation			
[1].1.4.4.12.1 [21].5.1.4.10.2 [23].5.1.4.10.2	A station with a queue of transmissions to send to a receiving station should link transmissions using the procedures set out in [1].1.4.4.12.	Y	Y	([66])
	Allowed DLPDU combinations			
[1].1.4.4.12.2 [21].5.1.4.10.3 [23].5.1.4.10.3	It shall be possible to combine the following DLPDUs: - RTS/DATA; - ACK/CTS; - ACK/DATA; - ACK/RTS.	Y	Y	
	Recommendation: Combined RTS/DATA DLPDUs			
[1].1.4.4.12.3 [21].5.1.4.10.4 [23].5.1.4.10.4	When a receiving station has selected a user data packet for transmission using the procedures of [1].1.4.4.3, it should also select the next user data packet with the highest priority and place an RTS DLPDU in the DLS burst containing the DATA DLPDU for the first user data packet, setting the T bit in the RTS to the inverse of T_t and append a response reservation type. (See notes)	Y	Y	
NOTE 1: Because the DATA DLPDU is unlimited in length, the RTS must precede the DATA DLPDU. However, since the RTS contains the inverse T bit of the transmitted DATA DLPDU (as it is for the subsequent DATA DLPDU), it must be processed second. NOTE 2: This recommendation also applies in cases where the short transmission procedures would normally be selected for transmission but for which there is an opportunity to combine it with the end of the previous long transmission procedure.				

[66] All specified DLPDU linkages are supported within ACTS/VDL4. Recommended DLPU linkages (combined RTS/DATA and combined ACK/RTS to different peers) may be activated or inhibited on demand during simulations (via an input parameter).

Requirement reference		Gnd	Air
	Combined ACK/CTS DLPDUs		
[1].1.4.4.12.4.1 [21].5.1.4.10.5 [23].5.1.4.10.5	On receipt of a RTS/DATA DLS burst, a station shall process the DATA DLPDU first according to the procedures of [1].1.4.4.6.5.1.	Y	Y
[1].1.4.4.12.4.1 [21].5.1.4.10.6 [23].5.1.4.10.6	If the station can find sufficient resources for a subsequent DATA DLPDU transfer, then the DLS burst containing the ACK DLPDU shall also contain a CTS DLPDU for the next DATA DLPDU transfer.	Y	Y
[1].1.4.4.12.4.1 [21].5.1.4.10.7 [23].5.1.4.10.7	A CTRL_CTS, INFO_CTS or UDATA_CTS DLPDU shall be sent in response to a CTRL_RTS, INFO_RTS or UDATA_RTS DLPDU respectively.	Y	Y
[1].1.4.4.12.4.2 [21].5.1.4.10.8 [23].5.1.4.10.8	In the case of CTRL_CTS and INFO_CTS DLPDUs, instead of the response reservation type required by the procedures of [1].1.4.4.6.5.1 the burst shall contain an information transfer request reservation field transmitted using the parameters defined in [1].Table II-1-63, indicating the number of slots reserved for transfer of the DATA DLPDU.	Y	Y
	Combined DATA/ACK DLPDUs		
[1].1.4.4.12.5 [21].5.1.4.10.9 [23].5.1.4.10.9	A receiving station which has data that would fit into a single slot DLS burst containing an ACK DLPDU to send back to the sending station, shall include its own DATA DLPDU in this DLS burst.	Y	Y
[1].1.4.4.12.5 [21].5.1.4.10.10 [23].5.1.4.10.10	The burst shall contain a unicast request reservation field with the parameters in [1].Table II-1-61 for the acknowledgement of the DATA DLPDU. (See note 1)	Y	Y
	Combined ACK/RTS DLPDUs		
[1].1.4.4.12.6 [21].5.1.4.10.11 [23].5.1.4.10.11	If a receiving station has data to send back to the sending station which cannot fit into a single slot DLS burst containing an ACK DLPDU, then the station shall combine an RTS DLPDU for its own DATA DLPDU in the DLS burst containing the ACK DLPDU and use the long transmission procedures for the data transfer.	Y	Y
	Recommendation - Combined ACK/RTS DLPDUs to different peers		
[1].1.4.4.12.7 [21].5.1.4.10.12 [23].5.1.4.10.12	If a station is sending an ACK DLPDU to one destination and has data to send to a different destination, then the station should include a unicast reservation field with sdf = 1 with the DLS burst containing the ACK and then transmit an RTS DLPDU to the new destination in the reserved slot. (See note 2)	Y	Y
NOTE 1: A station may combine a transport acknowledgement with the ACK if this can be produced in time. NOTE 2: This makes it possible for a ground station to link a series of transmissions to different destinations.			

CTRL DLPDU

Requirement reference		Gnd	Air
[1].1.4.4.13 [21].5.1.4.11.1 [22].5.3.3.4.1 [23].5.1.4.11.1	The CTRL DLPDU shall be used for the LME to establish and maintain links as defined in [1].1.5.	Y	Y

G.4 Link Management Entity sublayer

G.4.1 Services

General

Requirement reference		Gnd	Air
[20].5.4.1.1 [22].5.4.1.1	The LME shall support the provision of broadcast services.	Y	Y
[1].1.5.1 [21].5.2.1.1.1 [23].5.2.1.1.1	The services of the LME shall be as follows: a) link provision; and b) link change notification.	Y	Y

Link provision

Requirement reference		Gnd	Air
[1].1.5.1.1.1 [21].5.2.1.2.1 [23].5.2.1.2.1	Each Ground System and each Mobile System supporting air/ground point-to-point communication services shall include the functionality of a VDL Management Entity (VME).	Y	Y
[1].1.5.1.1.1 [21].5.2.1.2.2 [23].5.2.1.2.2	A VME shall be responsible for the data link management policy of the system.	Y	Y
[1].1.5.1.1.1.a) [23].5.2.1.2.2a	In a Mobile System the VME shall be responsible for determining with which Ground System(s) the Mobile System maintains datalink communications, at any given time.	N/A	Y
[1].1.5.1.1.1.b) [21].5.2.1.2.3	In a ground system, the VME shall be responsible for determining which mobile system(s) should be provided with data link communications as well as which ground station and mobiles (when the ground system supports multiple frequency operations) are to be assigned frequencies.	Y	N/A
[1].1.5.1.1.2 [21].5.2.1.2.4 [23].5.2.1.2.4	A VME shall have an LME for each peer LME.	Y	Y
[1].1.5.1.1.2 [21].5.2.1.2.5 [23].5.2.1.2.5a	A ground VME shall have an LME for every mobile system and a mobile VME shall have an LME for every ground system.	Y	Y
[1].1.5.1.1.2 [21].5.2.1.2.6 [23].5.2.1.2.6	An LME shall establish a link between a local data link entity (DLE) and a remote DLE associated with its peer LME.	Y	Y
[1].1.5.1.1.2.a) [21].5.2.1.2.7	A ground LME shall determine if a mobile station is associated with its peer mobile LME by comparing the station address; two mobile stations with identical station addresses are associated with the same LME.	Y	N/A
[1].1.5.1.1.2.b) [23].5.2.1.2.7a	A mobile LME shall determine if a ground station is associated with its peer ground LME by bit-wise logical ANDing the DLS address with the station ground system mask provided by the peer ground LME; two ground stations with identical masked DLS addresses are associated with the same LME.	N/A	Y
[1].1.5.1.1.3 [21].5.2.1.2.8 [23].5.2.1.2.8	Each ground and mobile LME shall monitor all transmissions (both DLS and VSS) from its peer's stations to maintain a reliable link between some ground station and a mobile while the mobile is in coverage of an acceptable ground station in the ground system.	Y	Y

Link change notifications

Requirement reference		Gnd	Air	
[1].1.5.1.2 [21].5.2.1.3.1 [23].5.2.1.3.1	The VME shall notify the Intermediate System - System Management Entity (IS-SME) of changes in link connectivity supplying information contained in the CTRL DLPDUs received.	Y	Y	([67])
NOTE: The IS-SME is a constituent entity in the ATN router, whose functions include managing the route initiation and termination procedures by responding to changes in subnetwork connectivity.				

G.4.2 Synchronization burst format

General

Requirement reference		Gnd	Air	
[1].1.5.2 [20].5.4.2.1.1 [22].5.4.2.1.1	All VDL Mode 4 stations shall transmit synchronization bursts to support link management.	Y	Y	([68])

Fixed and variable data fields

Requirement reference		Gnd	Air
[1].1.5.2.1 [20].5.4.2.2.1 [22].5.4.2.2.1	The synchronization burst shall consist of two portions: a fixed data field containing information that is sent with each synchronization burst and a variable data field containing additional system management information that does not need to be included in each synchronization burst.	Y	Y
NOTE 1: The variable data field can also include VSS user-specific information. NOTE 2: The fixed data field contains 55 bits of data consisting of bits 2 through 8 of octet 5 and all of octets 6 through 11 inclusive (the fixed data field begins after the source address (s) and message identification (mi) fields which consist of the first 4 octets and bit 1 of octet 5). The variable portion contains 54 bits of data consisting of octets 12 through 17 and bits 3 through 8 of octet 18. NOTE 3: Certain variable information fields have been assigned and are described in [1] Chapter 3.			

Fixed data field format (see [1].1.5.2.2)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

Variable data field format (see [1].1.5.2.3)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

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[67] In ACTS/VDL4, there is not IS-SME per say. Yet, such notification of link connectivity information and status is implemented for the computation of link-related statistics.

[68] The frequency at which a station transmits its synchronization bursts is driven by V11 and may be turned to 0 to support simulations where point-to-point communications take place on a dedicated channel.

Synchronization burst request

Requirement reference		Gnd	Air	
[1].1.5.2.4 [20].5.4.2.5.1 [22].5.4.2.5.1	To request that a station transmit a synchronization burst with a specific information field, a station shall transmit a general request burst to the appropriate application process as defined in [1].3.4.	N	N	([69])

Control (CTRL) DLPDU (see [1].1.5.2.5)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

Broadcast Link management burst (see [1].1.5.2.6)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

G.4.3 Control (CTRL) parameter formats

Encoding (see [1].1.5.3.1)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

VDL Mode 4 parameter identification (see [1].1.5.3.2)

In simulations, there is no requirement to support frame and/or parameter encoding (see also detailed explanation in G.2.2).

General purpose information parameters (see [1].1.5.3.3)

In simulations, there is no need for mobile or ground-based LMEs to transfert basic information to each other, as this may be case with operational systems.

Mobile-initiated information parameters (see [1].1.5.3.4)

In simulations, there is no need for a mobile LME to inform a ground LME about the capabilities or desires of that mobile, as this may be case with operational systems.

Ground-initiated modification parameters (see [1].1.5.3.5)

In simulations, there is no need for a ground LME to change the value of various parameters in one or more mobiles, as this may be case with operational systems.

[69] This feature, being not required for the targeted simulations, is not supported (so is the General Request, see G.2.19)

Ground-initiated information parameters (see [1].1.5.3.6)

In simulations, there is no need for a ground LME to inform one or more mobiles LMEs about the capabilities of that ground-based system, as this may be case with operational systems.

G.4.4 LME timers and parameters

General

Requirement reference		Gnd	Air
[1].1.5.4 [20].5.4.3a.1.1 [21].5.2.3.1.1 [23].5.2.3.1.1	The LME service shall implement the system parameters defined in [1].Table II-1-93.	Y	Y

[1].Table II-1-93: Management entity system parameters

Symbol	Parameter name	Min	Max	Default	Increment
L1	Maximum number of missed reservations	1	255	3	1
TL1	Maximum link overlap time initiating responding	 0 s 0 s	 255 s 255 s	 20 s 60 s	 1 s 1 s
TL2	Link initialization time	5 s	25 s	6 s	1 ms
TL3	Inter-miss timer	0 s	31 s	5 s	1 s
TL4	Leave event generation latency	0 s	255 s	20 s	1 s

Counter L1 (maximum number of missed reservations) and Timer TL3 (inter-miss timer)

Requirement reference		Gnd	Air
[1].1.5.4.1 [20].5.4.3a.2.1 [23].5.2.3.2.1	Parameter L1 shall be the maximum number of missed reservations before a station assumes that a peer station is unreachable.	Y	Y
[1].1.5.4.1 [20].5.4.3a.2.2 [23].5.2.3.2.2	There shall be one counter L1 per peer station as well as one per frequency (per peer station).	Y	Y
[1].1.5.4.1 [20].5.4.3a.2.3 [23].5.2.3.2.3	Counter L1 (both the all-frequencies and the appropriate frequency elements of the counter) shall be set to zero when a transmission is received from a peer station.	Y	Y
[1].1.5.4.1 [20].5.4.3a.2.4 [23].5.2.3.2.4	Counter L1 shall be incremented when no transmission is received from a peer station for which there was a prior reservation made by the peer station for itself if the particular L1 has not been incremented in the prior TL3 seconds.	Y	Y
[1].1.5.4.1 [20].5.4.3a.2.5 [23].5.2.3.2.5	When the all-frequencies counter L1 exceeds the maximum number of missed reservations (the value of parameter L1), the peer station shall be marked as unreachable in the peer entity contact table (PECT) (see [1].1.5.6.2) and it shall attempt to handoff to another ground station following the procedures of [1].1.5.7.	Y [70]	Y
[1].1.5.4.1 [20].5.4.3a.2.6 [23].5.2.3.2.6	Stations marked as unreachable shall be retained in the PECT for a period of time not less than 60 min.	Y	Y
[1].1.5.4.1 [20].5.4.3a.2.7 [23].5.2.3.2.7	When the single-frequency counter L1 exceeds the maximum number of missed reservations, the peer station shall be marked unreachable on that frequency.	Y	Y
NOTE 1: The reason that L1 is not incremented when no response is received in a slot that another station had reserved for its peer is the possibility that the reservation itself was lost and thus no reliable inference can be made on the reachability of the peer station. Lost or missed reservation in this context means no decoded transmission, i.e. the receiving station has not decoded a transmission it was expecting in a slot reserved for the sending station. NOTE 2: PECT entries are retained for a period of time in order to stabilize acquisition and track re-initialization performance for stations at the limits of coverage, and also to support potential search and rescue applications that may be developed in the future. Reservations for unreachable stations are retained in the reservation table and allowed to expire normally. These reservations represent real transmissions that may be expected to occur at the indicated times.			

[70] With the exception that ground station never attempt to handoff to another ground station.

Timer TL1 (maximum link overlap time)

Requirement reference		Gnd	Air
[1].1.5.4.2 [21].5.2.3.2.1 [23].5.2.3.3.1	Timer TL1 shall be set to the maximum time that initiating and responding LMEs will maintain the old link during handoffs.	Y	Y
[1].1.5.4.2 [21].5.2.3.2.2 [23].5.2.3.3.2	The LME initiating the handoff shall start its Timer TL1 when it receives an CTRL_RSP_HO.	N (*)	Y
[1].1.5.4.2 [21].5.2.3.2.3 [23].5.2.3.3.3	The LME responding to the handoff shall start its Timer TL1 when it transmits its CTRL_RSP_HO.	Y	N (*)
[1].1.5.4.2 [21].5.2.3.2.4 [23].5.2.3.3.4	The initiating LME shall never restart its Timer TL1.	N (*)	Y
[1].1.5.4.2 [21].5.2.3.2.5 [23].5.2.3.3.5	The responding LME shall restart its Timer TL1 if it retransmits a CTRL_RSP_HO.	Y	N (*)
[1].1.5.4.2 [21].5.2.3.2.6 [23].5.2.3.3.6	Timer TL1 shall be cancelled if either the old or new link is prematurely disconnected.	Y	Y
[1].1.5.4.2 [21].5.2.3.2.7 [23].5.2.3.3.7	After TL1 expires, each LME shall silently disconnect its half of the old link.	Y	Y
NOTE: There is one timer TL1 per LME.			

(*) ACTS/VDL4 only supports air-initiated handoffs.

Parameters TL2 (link initialization time)

Requirement reference		Gnd	Air
[1].1.5.4.3.1 [21].5.2.3.3.1 [23].5.2.3.4.1	The parameter TL2 shall control the re-transmission of CTRL DLPDU for which an expected response has not been received.	N/A	Y
[1].1.5.4.3.2 [21].5.2.3.3.2 [23].5.2.3.4.2	Timer TL2 shall be set after the transmission of a CTRL for which a response is expected.	N/A	Y
[1].1.5.4.3.2 [21].5.2.3.3.3 [23].5.2.3.4.3	Timer TL2 shall be cleared upon receipt of a CTRL DLPDU from the peer LME.	N/A	Y
[1].1.5.4.3.2 [21].5.2.3.3.4 [23].5.2.3.4.4	If Timer TL2 expires, the LME shall attempt to handoff to another ground station in accordance with the procedures of [1].1.5.7.	N/A	Y

Timer TL4 (leave generation latency)

Requirement reference		Gnd	Air
[1].1.5.4.4 [21].5.2.3.5.1 [23].5.2.3.5.1	Timer TL4 shall control the triggering of Leave events.	N	Y
[1].1.5.4.4 [21].5.2.3.5.2 [23].5.2.3.5.2	Timer TL4 shall be set whenever the LME initiates a handoff because of an invalid link.	N	Y
[1].1.5.4.4 [21].5.2.3.5.3 [23].5.2.3.5.3	Timer TL4 shall be cancelled upon completion of a successful handoff.	N	Y
[1].1.5.4.4 [21].5.2.3.5.4 [23].5.2.3.5.4	If Timer TL4 expires, the LME shall generate a LEAVE event as described in [1].Chapter 2.	N	Y
[1].1.5.4.4 [21].5.2.3.5.5 [23].5.2.3.5.5	Timer TL4 shall never be restarted.	N	Y
NOTE 1: There is one TL4 timer per peer station. NOTE 2: Instances of when a link may be considered invalid are upon expiration of Q5num or Q5wait, upon surpassing of L1 and upon receipt of a DM/DISC or a UCTRL_DM.			

G.4.5 LME procedures

Synchronization burst procedures

Requirement reference		Gnd	Air
[1].1.5.5.1.a) [20].5.4.4.1.1 [22].5.4.4.1.1	All stations shall transmit the appropriate synchronization burst defined in [1].1.5.2 depending on whether it is a mobile station or a ground station.	Y	Y
[1].1.5.5.1.a) [20].5.4.4.1.2 [22].5.4.4.1.2	If the synchronization burst is transmitted with a periodic broadcast protocol, it shall use default QoS parameters except as defined in [1].Table II-1-109.	Y	Y
[1].1.5.5.1.a) [20].5.4.4.1.3 [22].5.4.4.1.3	If the synchronization 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.	Y	Y

[1].Table II-1-109: Synchronization burst parameters

Symbol	Parameter name	Default
V11	Nominal periodic rate	6
Q1	Priority	14
Q2a	Slot selection range constraint for level 1	380 NM
Q2b	Slot selection range constraint for level 2	380 NM
Q2c	Slot selection range constraint for level 3	0 NM
Q2d	Slot selection range constraint for level 4	380 NM
Q3	Replace queued data	TRUE

Requirement reference		Gnd	Air	
[1].1.5.5.1.b) [20].5.4.4.1.4 [22].5.4.4.1.4	The values of the subfields shall be the latest available data that can be obtained by the station at the start of the slot that is two slots before the first slot of the intended transmission.	Y	Y	
[1].1.5.5.1.c) [20].5.4.4.1.5 [22].5.4.4.1.5	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.	Y	Y	
	Transmission of synchronization bursts supporting applications			
[1].1.5.5.1.1.1 [22].5.4.4.1.6	A station shall transmit synchronization bursts in accordance with a request from a peer station as described in [1].1.5.2.4, at the specified rate, and containing the information (in) field corresponding to the requested information field ID (r-id).	N	N	([71])
[1].1.5.5.1.1.2 [20].5.4.4.1.6 [22].5.4.4.1.6a	The station shall transmit additional synchronization bursts required to meet the demands of any application.	N	N	([72])
[1].1.5.5.1.1.2 [22].5.4.4.1.6b	In the event that an application request requiring the transmission of synchronization bursts is delivered by means of a directed request, the required burst shall be transmitted in the slots reserved by the directed request protocol.	N	N	([73])
NOTE: The interaction between the LME and the application of specific requirements for transmission of synchronization bursts is a local issue.				

Requirement reference		Gnd	Air	
	Mobile stations			
[1].1.5.5.1.2 [22].5.4.4.1.6c	Whenever a mobile station is not directed to transmit synchronization bursts on any frequency, it shall transmit mobile synchronization bursts at least once per M1 (number of slots per superframe) slots on all GSCs, which it can receive.	Y	Y	([74])
[1].1.5.5.1.2 [22].5.4.4.1.6d	When transmitting autonomously on the GSCs, mobile stations shall use the standard parameters defined in [1].Table II-1-65.	Y	Y	
NOTE: Upon termination of all directed synchronization burst transmissions on a channel(s) other that the GSCs, mobile stations may employ the network entry procedures as described in [1].1.5.5.3 to quickly enter the GSC network(s).				

[71] General request are not supported (see G.2.19)

[72] Same as above note.

[73] Directed request are not supported (see G.2.16)

[74] Driven by V11.

Requirement reference		Gnd	Air	
	Ground stations			
	Recommendation			
[1].1.5.5.1.3.2 [20].5.4.4.1.7	A set of ground stations should ensure that sufficient synchronization bursts are available to support the derivation of secondary timing.	N	N	([75])
	Procedures for conflict resolution			
[1].1.5.5.1.4 [20].5.4.4.1.8 [22].5.4.4.1.8	For the purposes of assessing whether or not a reservation conflicts with another reservation for a synchronization burst, the station shall apply the procedures defined in [1].1.3.6.5.	Y	Y	
[1].1.5.5.1.4 [20].5.4.4.1.9 [22].5.4.4.1.9	In this case, the quality of service parameters defined in [1].Table II-1-110 or user supplied parameters shall be applied to the synchronization burst reservation.	Y	Y	
NOTE: These parameters place tighter constraint 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.				

[1].Table II-1-110: Synchronization burst parameters for conflict resolution

Symbol	Parameter name	Value
Q1	Priority	As per information field
Q2a	Slot selection range constraint for level 1	360 NM
Q2b	Slot selection range constraint for level 2	360 NM
Q2c	Slot selection range constraint for level 3	360 NM
Q2d	Slot selection range constraint for level 4	360 NM

Peer entity contact table (PECT)

Requirement reference		Gnd	Air
[1].1.5.5.2 [20].5.4.4.2.1 [22].5.4.4.2.1	Every station shall maintain a table of all known stations.	Y	Y
[1].1.5.5.2 [20].5.4.4.2.2 [22].5.4.4.2.2	For each station, the table shall include the type of the station, a copy of the last of each type of broadcast burst, the time of the last transmission and a L1 counter.	Y	Y
[1].1.5.5.2 [20].5.4.4.2.3 [22].5.4.4.2.3	The ability to reach a peer station shall be assumed lost after L1 missed reservations.	Y	Y

Network entry protocol specifications

Not required for the targeted simulations, the network entry procedure is not implemented.

[75] Support for the secondary timing is not required (see also G.1.4)

G.4.6 Types and procedures of CTRL DLPDU

Requirement reference		Gnd	Air
[1].1.5.6 [21].5.2.4.1 [23].5.2.4.1	The mobile and ground LMEs shall use the CTRL DLPDU types listed in [1].Table II-1-116a as well as the procedures described in [1].1.5.7 to provide a reliable connection between the mobile and ground-based system.	Y	Y
[1].1.5.6 [21].5.2.4.2 [23].5.2.4.2	If an LME receives any valid CTRL_HO frame from a system with which it does not have a link, it shall respond with a CTRL_LCR with the 'd' bit set to 1 in the Protocol Violation Cause Code.	N/A	N [(76)]

G.4.7 CTRL transmission procedures

Frequency management procedures

Requirement reference		Gnd	Air
[1].1.5.7.1 [23].5.2.5.a.1	The mobile LME shall use the procedures outlined in [1].1.5.7.1.1 to [1].1.5.7.1.2 to acquire a frequency on which reliable VDL services are available.	N/A	Y
	Frequency search		
[1].1.5.7.1.1 [23].5.2.5.a.2	The mobile LME shall initiate the frequency search procedure on system initialization or after link disconnection, if there are no ground stations that provide the requested service within the operational coverage (range) of the mobile.	N/A	Y
[1].1.5.7.1.1 [23].5.2.5.a.3	The mobile LME shall attempt to identify a frequency on which the required VDL service is available by tuning the radio to the GSCs and/or to other frequencies on which it knows a-priori that VDL service is available.	N/A	Y
[1].1.5.7.1.1 [23].5.2.5.a.4	On the basis of information contained in the GSIF, it shall select an appropriate channel to receive the required service.	N/A	Y
	Frequency recovery		
[1].1.5.7.1.2 [23].5.2.5.a.5	The mobile LME shall initiate the frequency recovery procedure if it can no longer establish a link on the current frequency or if the VSS indicates that the current frequency is congested.	N/A	Y
[1].1.5.7.1.2 [23].5.2.5.a.6	It shall tune the radio to an alternate frequency using the data in the Frequency Support List or Directory of Service message previously received on the current link.	N/A	Y

Link connectivity procedures

Requirement reference		Gnd	Air
[1].1.5.7.2 [21].5.2.5.1.1 [23].5.2.5.1.1	The ground LME shall use the following procedures to maintain connectivity across the VHF link: a) ground station identification; b) initial link establishment; c) mobile-initiated handoff; d) mobile-requested ground-initiated handoff; e) ground-initiated handoff; f) ground-requested mobile-initiated handoff; g) ground-requested mobile-initiated handoff; h) autotune.	Y	N/A

[76] Only air-initiated handoffs are supported.

Ground Station Identification

Requirement reference		Gnd	Air
[1].1.5.7.3 [21].5.2.5.2.1	A ground station providing a VDL Mode 4 service shall send a GSIF at least once every minute on each of the channels on which it offers the service, as well as on the GSCs by broadcasting a UCTRL (ucid = 0) with parameters as per [1].Table II-1-116c.	Y	N/A
[1].1.5.7.3 [21].5.2.5.2.2	The operator of that ground station shall ensure that, in addition to transmitting GSIFs on the service frequency, GSIFs are transmitted on the GSCs.	Y	N/A
[1].1.5.7.3 [23].5.2.5.2.3	Mobile LMEs receiving a GSIF shall process its content to identify the functionality of the ground station as well as the correct operational parameters to be used when communicating with it.	N/A	Y
[1].1.5.7.3 [23].5.2.5.2.4	Mobile LMEs which have a connection with the transmitting ground station shall process only information parameters as per [1].Table II-1-116a, [1].Table II-1-116b, [1].Table II-1-116c.	N/A	Y

Link establishment

Requirement reference		Gnd	Air
[1].1.5.7.4 [23].5.2.5.3.a	The mobile LME shall initiate the link establishment procedure with a ground station to establish an initial link with the ground-based system.	N/A	Y
[1].1.5.7.4 [23].5.2.5.3.b	Whenever the link is disconnected (e.g. on receipt of DM/DISC or DM/FRMR), a mobile shall initiate link establishment according to the local link management policy if no links remain.	N/A	Y
	Mobile LME initiation		
[1].1.5.7.4.1.1 [23].5.2.5.3.c	The mobile LME shall choose a ground station with which it wishes to establish a link based on its capability to support a link and so as to maximize the likely duration of the connection to the ground station (see note).	N/A	Y
[1].1.5.7.4.1.2 [23].5.2.5.3.d	The mobile LME shall then attempt to establish a link with the chosen ground station by sending a CTRL_CMD_LE (re=1) DLPDU.	N/A	Y
[1].1.5.7.4.1.2 [23].5.2.5.3.e	This DLPDU shall include the mandatory parameters as per [1].Table II-1-116b and also any optional parameters for which the mobile LME does not wish to use the default value.	N/A	Y
[1].1.5.7.4.1.2 [23].5.2.5.3.f	If the mobile LME has received a GSIF from the ground station to which it is transmitting the CTRL_CMD_LE (re=1), then it shall use the parameters as declared; otherwise, it shall use the default parameters.	N/A	Y
	General ground response		
[1].1.5.7.4.2 [21].5.2.5.3.1	If the ground LME receives the CTRL_CMD_LE, it shall confirm link establishment by sending a CTRL_RSP_LE DLPDU containing the parameters as per [1].Table II-1-116a.	Y (77)	N/A
[1].1.5.7.4.2 [21].5.2.5.3.2	The ground LME shall include in the CTRL_RSP_LE any optional parameters for which it is not using the default values.	N	N/A
[1].1.5.7.4.2 [21].5.2.5.3.3	If the CTRL_RSP_LE includes the Autotune parameter then the Replacement Ground Station List parameter shall be included indicating the ground stations on the new frequency with which the mobile LME can establish a new link using the operating parameters specified in the CTRL_RSP_LE.	N	N/A
[1].1.5.7.4.2 [21].5.2.5.3.4	If the CTRL_RSP_LE does not include the Autotune parameter, the ground LME shall include the Replacement Ground Station List parameter if it wishes to indicate the ground stations which can be reached on the current frequency using the same operating parameters as the transmitting station.	N	N/A
	Exceptional cases		
[1].1.5.7.4.3 [21].5.2.5.3.5	If an LME receiving the CTRL_CMD_LE cannot establish the link with the sending LME, then it shall transmit a CTRL_RSP_LCR instead of a CTRL_RSP_LE.	N (78)	N/A
[1].1.5.7.4.3 [23].5.2.5.3.6	If the parameters in the CTRL_RSP_LE from the ground LME are not acceptable to the mobile LME, then the mobile LME shall transmit a DM/DISC to the ground.	N/A	N (79)
[1].1.5.7.4.3 [23].5.2.5.3.7	If the Autotune parameter is included in the CTRL_RSP_LE and the mobile LME is unable to perform the autotune, then the mobile LME shall respond with an CTRL_CMD_LCR (re=0); the link established on the current frequency will not be affected.	N/A	N
NOTE: To maximize the likely connection time, the mobile can take account of mobile position, intent, ground station position, the signal quality of all received uplink bursts and on information in any received GSIFs.			

[77] Air-ground parameter negotiation is not required for simulations: default parameters are always used from the ground system and assumed by airborne stations.

[78] During simulations, validly received CTRL_CMD_LE on the ground side always leads to the sending of a link establishment response (CTRL_RSP_LE).

[79] Default parameters being always proposed by ground systems, they are always acceptable to the mobile LME.

Mobile-initiated handoff

Requirement reference		Gnd	Air	
[1].1.5.7.5 [23].5.2.5.4.a	If a mobile LME implements this section, then it shall set the "i" bit in the Protocol Options parameter to 1; otherwise, it shall set the "i" bit to 0.	N/A	Y	
	Mobile handoff			
[1].1.5.7.5.1 [23].5.2.5.4.b	Once the mobile LME has established a link to a ground station, it shall monitor the VHF signal quality on the link and the transmissions of the other ground stations.	N/A	Y	
[1].1.5.7.5.1 [23].5.2.5.4.c	The mobile LME shall establish a link to a new ground station if any of the following events occur: a) the VHF signal quality on the current link is determined, in accordance with local link management policy, to be insufficient to maintain reliable communications and the signal quality of another ground station is significantly better; b) TL2 seconds have elapsed since the LME initiated the request to send any burst to the current ground station; c) The peer station has become unreachable as defined in [1].1.5.4.1; d) Timer TM2 expires; e) The mobile LME is at a position which, in accordance with local link management policy, requires the station to establish a link with a new ground station.	N/A	Y	
[1].1.5.7.5.1 [23].5.2.5.4.d	If timer TM2 expires, the mobile LME shall autonomously tune to an alternate frequency (provided in a frequency support list) before initiating the handoff.	N/A	Y	
	Site selection preference			
[1].1.5.7.5.2 [23].5.2.5.4.f	From among those ground stations with acceptable link quality, the mobile LME shall prefer to handoff to a ground station which indicates (in the GSIF) accessibility to the air-ground router(s) to which the mobile DTE has subnetwork connections.	N/A	Y	
	Recommendation			
[1].1.5.7.5.3 [23].5.2.5.4.g	If a mobile has commenced approach to its destination airport and its current link is with a ground station that does not offer service at that airport, it should handoff to a ground station which indicates in its Airport Coverage Indication parameter that it offers service at that airport.	N/A	N [80]	
	Interaction of LMEs			
[1].1.5.7.5.4 [21].5.2.5.4.1 [23].5.2.5.4.1	When a mobile VME hands off from a ground station in one ground-based system (and thus associated with one LME) to a ground station in another ground-based system (and thus associated with a different LME in the mobile), the new LME shall use the link establishment procedures.	N/A	Y	
[1].1.5.7.5.4 [21].5.2.5.4.2 [23].5.2.5.4.2	The old LME shall send a DM/DISC when directed by the VME. (See note)	N	N	([81])
	General ground response			
[1].1.5.7.5.5 [21].5.2.5.4.3	If the ground LME receives the CTRL_CMD_HO, it shall confirm link handoff by sending a CTRL_RSP_HO DLPDU containing the parameters as per [1].Table II-1-116b and [1].Table II-1-116c.	Y	N/A	
[1].1.5.7.5.5 [21].5.2.5.4.4	The ground LME shall include in the CTRL_RSP_HO the optional parameters for which it is not using the default values.	Y	N/A	
[1].1.5.7.5.5 [21].5.2.5.4.5	If the CTRL_RSP_HO includes the Autotune parameter, then the Replacement Ground Station List parameter shall be included to indicate the ground stations with which the mobile LME can establish a new link on the new frequency, using the operating parameters specified in the CTRL_RSP_HO.	N	N/A	([82])
[1].1.5.7.5.5 [21].5.2.5.4.6	If the CTRL_RSP_HO does not include the Autotune parameter, the ground LME shall include the Replacement Ground Station List parameter if it wishes to indicate the ground stations which can be reached on the current frequency using the same operating parameters as the transmitting station.	N	N/A	

[80] Such information is not available in simulations.

[81] Old links are silently disconnected according to [1].1.5.4.2.

[82] The support of Autotune is not required for targeted simulations.

Requirement reference		Gnd	Air
	Disconnecting old link		
[1].1.5.7.5.6 [21].5.2.5.4.7 [23].5.2.5.4.7	If the new and old ground stations are associated with different systems, then the procedures of [1].1.5.7.5.4 shall be followed.	N/A	N [83]
[1].1.5.7.5.6 [21].5.2.5.4.8 [23].5.2.5.4.8	Otherwise, the mobile LME shall set Timer TL1 when it receives the CTRL_RSP_HO.	N/A	Y
[1].1.5.7.5.6 [21].5.2.5.4.9 [23].5.2.5.4.9	The ground LME shall set Timer TL1 after it transmits the CTRL_RSP_HO.	Y	N/A
[1].1.5.7.5.6 [21].5.2.5.4.10 [23].5.2.5.4.10	Both stations shall continue to operate on the old link until their respective Timer TL1 expires, after which each will consider the link disconnected without sending or receiving a DM/DISC.	Y	Y
	Exceptional cases		
[1].1.5.7.5.7 [21].5.2.5.4.11	If the ground LME cannot satisfy the CTRL_CMD_HO, then it shall transmit a CTRL_RSP_LCR instead of a CTRL_RSP_HO.	N [84]	N/A
[1].1.5.7.5.7 [21].5.2.5.4.12	In this case, the current link shall not be affected.	N	N/A
[1].1.5.7.5.7 [23].5.2.5.4.13	If more than TL2 seconds have elapsed since the LME initiated the request to send the CTRL_CMD_HO (re = 1), the aircraft LME shall attempt to handoff to another ground station; the current link will not be affected.	N/A	Y
[1].1.5.7.5.7 [23].5.2.5.4.14	If the mobile LME cannot perform the autotune, it shall transmit a CTRL_CMD_LCR (re=0); the current link will not be affected.	N/A	N
[1].1.5.7.5.7 [23].5.2.5.4.15	If the parameters in the CTRL_RSP_HO are not acceptable to the mobile LME, then the mobile LME shall transmit a DM/DISC to the ground on the new link.	N/A	N ([85])
NOTE: Optimally the old link should not be disconnected until after the new link is capable of carrying application data. This subject is however outside the scope of this document.			

Mobile-requested ground-initiated handoff

Mobile-requested ground-initiated handoffs are not supported.

Ground-initiated handoff

Ground-initiated handoffs are not supported.

Ground-requested mobile-initiated handoff

Ground-requested mobile-initiated handoffs are not supported.

[83] In ACTS/VDL4, handoffs are always initiated between ground stations of the same system.

[84] In ACTS/VDL4, a ground station always responds (i.e. accepts) to air-initiated handoffs.

[85] In ACTS/VDL4, ground responses to handoffs are always acceptable to mobile LME.

Ground-requested broadcast handoff

Ground-requested broadcast handoffs are not supported.

Ground-commanded autotune

Not required for the targeted simulations, ground-commanded autotune are not supported.

Appendix H. Physical layer CCI performance validation and cross-check

H.1 Introduction

As part of the cross-check of VPS and ACTS validation tests were carried out on both ACTS and VPS to illustrate the behaviour of the physical layer and to confirm that both simulators met the VDL4 MOPS requirements.

In particular the test looked to determine that the physical layer models had a Co-Channel Interference (CCI) performance of at least 12dB ie the models could decode a wanted signal in the presence of co-channel interference with at least a 2% MER if the signal power was 12dB greater than the interference power.

H.2 Test description

The sections below describe the step by step guide for the test to demonstrate the CCI performance of the physical layer model implemented in a VDL Mode 4 simulator.

H.2.1 Required inputs and outputs

Required tools:

- VDL Mode 4 simulator and configuration files
- MS Excel

Inputs:

- Message input script
- VDL Mode 4 station positions
- Noise value (Nx) associated with the VDL Mode 4 physical layer model implemented in the simulator. This is the noise value associated with a typical VDL Mode 4 receiver.

Outputs:

- Statistics recording the number of successful message decodes at the VDL Mode 4 receiver under test from each transmitter

H.2.2 Test steps

Step 1: Configure a wanted input signal to the VDL Mode 4 physical layer (implemented in the VDL Mode 4 simulator) consisting of a single slot transmission with a Signal-to-Noise Ratio (SNR) of 15dB. The SNR is the ratio of the power of the input signal to the power of the noise floor of the receiver (Nx). Note this value is the SNR that is presented to the decoder in a VDL Mode 4 receiver ie after taking into account any gains and losses due to propagation, cables, antennas etc. The wanted signal is the transmission that the VDL Mode 4 receiver is trying to decode.

The following is a suggested implementation for achieving the above step.

- Configure two VDL Mode 4 stations in the VDL Mode 4 simulator. Station 1 is the receiving station (RX1) at which we will test the CCI performance of the physical layer implemented in the simulator. Station 2 is a transmitter used to generate a wanted input signal to the VDL Mode 4 receiver of RX1.
- Configure RX1 as a static station at a fixed location. Configure TX2 as a static station at a fixed distance D2 from RX1. D2 should be chosen so that the signal strength from a transmission from TX2 received at the decoder at RX1 results in a SNR of 15dB [86]ie all antenna gains, cable losses and propagation losses applied by the simulator should be taken into account.
- Configure TX2 to make single slot point-to-point transmissions to RX1 using the Unicast protocol[87]. The transmissions should be made in fixed slots using the fixed access protocol.
- Configure TX2 to make 100 single slot transmissions to RX1 in fixed slots every 20 slots. EG slot numbers 4500, 4520 ….6460, 6480. Configure the following Unicast request system parameters to be applied to each transmission. These parameters are to ensure that RX1 will reply with the Acknowledgement before the next transmission from TX2 and that TX2 will not attempt any retransmissions:

Symbol	**Parameter name**	**Value**
V32	Minimum response delay	2
V33	Maximum response delay	8
V34	Source/destination control	0
V35	Broadcast control	0
Q5num	Number of transmission attempts	1

Step 2: Configure an interference input signal to the VDL Mode 4 physical layer consisting of a single slot transmission with a Signal-to-Noise Ratio (SNR) of 11dB. This SNR value results in a Signal-to-Interference Ratio (SIR) of 4dB between the wanted signal and interference signal. Note this value is the SIR that is presented to

[86] The calculation of aircraft position is relatively straightforward and we can enter the traffic at the calculated position using the standard VPS inputs. Note however that the transmitter/receiver model we use adds a randomly generated gain to mimic the effects of variation between aircraft. Therefore the actual signal strength varies from the intended value by a small dB offset. This offset can be obtained from the output files and used to correct the presentation of the results.

[87] We are not sure whether ACTS can specifically generate a “unicast protocol”. However, a similar effect would be achieved by sending a short data transmission which can be encapsulated in a single slot transmission.

the decoder in the VDL Mode 4 receiver ie after taking into account any gains and losses due to propagation, cables, antennas etc. The interference signal is applied to the VDL Mode 4 physical layer at the same time as the wanted signal.

The following is a suggested implementation for achieving the above step.

- Configure a third VDL Mode 4 station in the VDL Mode 4 simulator. Station 3 is a transmitter used to generate an interference input signal to the VDL Mode 4 receiver of RX1.
- Configure TX3 as a static station at a fixed distance D3 from RX1. D3 should be chosen so that the signal strength from a transmission from TX3 received at the decoder at RX1 results in a SIR of 4dB when compared to the wanted signal from TX2 ie all antenna gains, cable losses and propagation losses applied by the simulator should be taken into account.
- Configure TX3 to make single slot point-to-point transmissions to RX1 using the Unicast protocol. The transmissions should be made in fixed slots using the fixed access protocol.
- Configure TX3 to make 100 single slot transmissions to RX1 in the same fixed slots as TX2. EG slot numbers 4500, 4520 …6460, 6480. Configure the following Unicast request system parameters to be applied to each transmission. These parameters are to ensure that RX1 will reply with the Acknowledgement before the next transmission from TX3 and that TX3 will not attempt any retransmissions. Note it is not expected that RX1 will decode any transmissions from TX3.

Symbol	Parameter name	Value
V32	Minimum response delay	2
V33	Maximum response delay	8
V34	Source/destination control	0
V35	Broadcast control	0
Q5num	Number of transmission attempts	1

Step 3: Apply both the wanted signal and the interference signal to the VDL Mode 4 physical layer and record whether the wanted signal was successfully decoded.

Step 4: Repeat step 3 one hundred times, recording whether the wanted signal was successfully decoded each time.

Step 5: Calculate the Message Error Rate (MER) associated with a SNR of 15dB and SIR of 4dB as follows:

MER = (100 – number of successfully decoded messages)/100

Step 6: Repeat steps 1 to 5 for the following SIR values: 6, 8, 10, 12, 14, 16, 18, 20, 24, 26, 28, 30, 32 and 34dB.

The following is a suggested implementation for achieving the above step.

- Configure additional VDL Mode 4 stations in the VDL Mode 4 simulator. Station n is a transmitter used to generate an interference input signal to the VDL Mode 4 receiver of RX1.
- Configure TXn as a static station at a fixed distance Dn from RX1. Dn should be chosen so that the signal strength from a transmission from TXn received at the decoder at RX1 results in one of the SIR values defined in step 6, when compared to the wanted signal from TX2.
- Configure TX2 to make additional single slot point-to-point transmission to RX1 using the Unicast protocol. The transmissions should be made in fixed slots using the fixed access protocol. For each SIR value, configure TX2 to make 100 single slot transmissions to RX1 in fixed slots every 20 slots. EG slot numbers 6500, 6520 ….8460, 8480 etc.
- Configure TXn to make single slot point-to-point transmissions to RX1 using the Unicast protocol. The transmissions should be made in fixed slots using the fixed access protocol.
- Configure TXn to make 100 single slot transmissions to RX1 in the same fixed slots as TX2. EG slot numbers 6500, 6520 ….8460, 8480 etc. Configure the following Unicast request system parameters to be applied to each transmission. These parameters are to ensure that RX1 will reply with the Acknowledgement before the next transmission from TXn and that TXn will not attempt any retransmissions. Note it is note expected that RX1 will decode any transmissions from TXn.

Symbol	Parameter name	Value
V32	Minimum response delay	2
V33	Maximum response delay	8
V34	Source/destination control	0
V35	Broadcast control	0
Q5num	Number of transmission attempts	1

Step 7: Plot the results on a chart of MER values against SIR (for an SNR of 15dB).

Step 8: Repeat steps 1 to 7 for the following SNR values: 20, 25, 30 and 35 dB.

The following is a suggested implementation for achieving the above step.

- Configure additional VDL Mode 4 stations in the VDL Mode 4 simulator. Station m (TXm) is a transmitter used to generate a wanted input signal to the VDL Mode 4 receiver of RX1.
- Configure TXm as a static station at a fixed distance Dm from RX1. Dm should be chosen so that the signal strength from a transmission from TXm received at the decoder at RX1 results in one of the SNR values defined in step 8.
- Configure TXm to make single slot point-to-point transmissions to RX1 using the Unicast protocol. The transmissions should be made in fixed slots using the fixed access protocol. For each SIR value, configure TXm to make 100 single slot transmissions to RX1 in fixed slots every 20 slots.
- For each TXm configure additional transmitters TXn to generate interference input signals to the VDL Mode 4 receiver of RX1 with the defined SIR values. Each TXn should be configured to transmit in the same slots as TXm. Note TXn should not transmit in the same slots as each other.
- Configure the following Unicast request system parameters to be applied to each transmission.

Symbol	**Parameter name**	**Value**
V32	Minimum response delay	2
V33	Maximum response delay	8
V34	Source/destination control	0
V35	Broadcast control	0
Q5num	Number of transmission attempts	1

H.2.3 Results of cross-check of simulator physical layer performance

The sections below describe the results of the tests on the performance of the physical models implemented in ACTS and VPS. These results illustrate behaviour of the physical layer and confirm that both simulators meet the following VDL4 MOPS requirements.

- Receiver sensitivity: the MOPS requirements states that a 2% MER should be achieved for a signal level of -98dBm.
- CCI performance: the MOPS requirements states that a 2% MER should be achieved for a SIR of 12dB at a signal level of -87dBm.

ACTS results

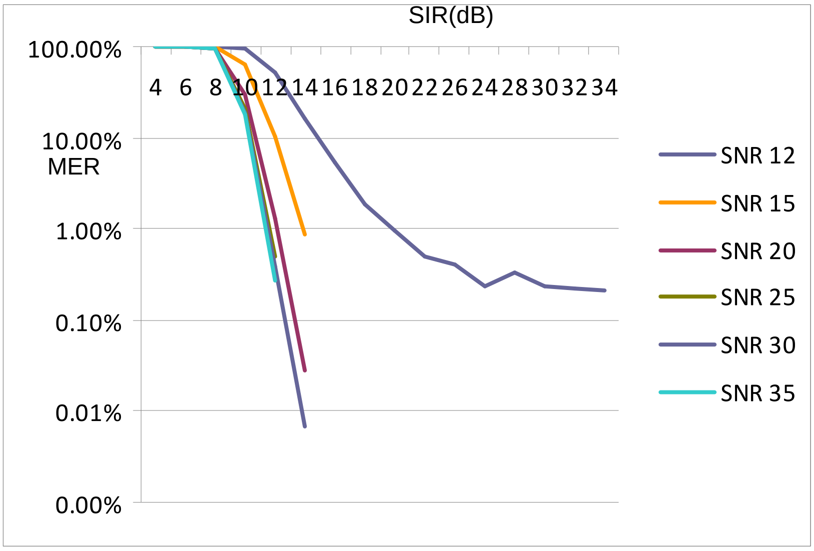

Figure: Results of ACTS physical layer validation test

The noise value used in the VPS physical layer model was -110dBm. Therefore the relevant SNR values for comparison with the MOPS requirements are:

- Receiver sensitivity: SNR = 12dB (-98+110).
- CCI performance: SNR value = 23dB (-87+110)

The ACTS results for SNR=12dB show that MER<2% at high SIR values. These results demonstrate compliance with the MOPS receiver sensitivity requirement.

The ACTS results for SNR=20dB and SNR=25dB show that the MER<2% at SIR values = 12dB. These results demonstrate compliance with the MOPS CCI requirement.

VPS results

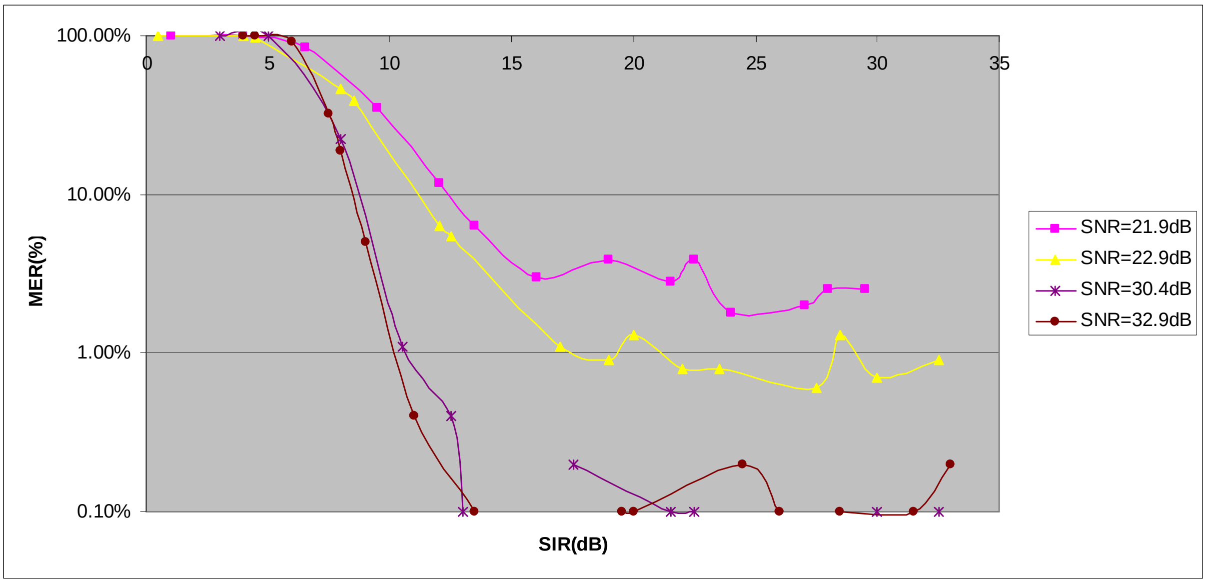

Figure: Results of VPS physical layer validation test

The noise value used in the VPS physical layer model was -119.8dBm. Therefore the relevant SNR values for comparison with the MOPS requirements are:

- Receiver sensitivity: SNR = 21.8dB (-98+119.8).
- CCI performance: SNR value = 32.8dB (-87+119.8)

The VPS results for SNR=21.9 dB show that MER=2% at high SIR values. At SNR=22.9dB the MER<2% at high SIR values. These results demonstrate compliance with the MOPS receiver sensitivity requirement.

The VPS results for SNR=30.4 dB and SNR=32.9 dB show that the MER<2% at SIR values < 12dB. These results demonstrate compliance with the MOPS CCI requirement.

H.2.4 Conclusions

Both VPS and ACTS implement MOPS compliant physical layer models. However, it was noted that the CCI performance of the physical layer model in VPS was approximately 10dB compared to 12dB in ACTS. The VPS CCI performance represents the expected performance of VDL4 radios but is better than the 12dB minimum performance specified in the MOPS.

Appendix I. Cross-check exercise and VPS releases

I.1 VPS releases

The VPS release that was available at the time this simulation study was launched corresponded to the product used to run previous simulation campaign. The corresponding release is known as VPS build 7 (released in Feb. 2004; hereafter referred to as VPS7), that was used to produce previous campaign reports ([6], [7]).

During the present study's preliminary cross-check activities (section 2), a number of fixes were made, bringing the VPS release to build 7a (released in Dec. 2005; hereafter referred to as VPS7a). The fixes are:

- Post processor (minor fix): bug in interpreting logs of delay statistics resulting in extreme delays for the affected transmissions;
- Main processor (minor fix): bug that caused a successful fragment to be re-sent multiple times, affecting Long transmissions;
- Main processor (major fix): bug in seeding of random generator module resulting in "stuck" outcome for relatively long periods of time. The undesirable effect was an inflated channel access time given by the random procedure.

The first two fixes were affecting the computation of the statistics themselves – but not the functional procedures of the simulated protocols. The effects of the bugs were non-significant (only few occurrences – not affecting significantly the overall results).

The third fix only had significant impact on the functional procedures, thus affecting significantly the associated results.

I.2 VPS builds and associated results

The following table provides comparison of the results provided by the various VPS builds[88] (on some simplistic cross-check scenarios only).

Cross-check Scenario	Transit delays (i.e. one-way delays)						Round-trip delays (i.e. two-way delays)						Success Rate	
	Avg. (s)		Std. Dev. (s)		On time 5s (%)		Avg. (s)		Std. Dev. (s)		On time 8s (%)		(%)	
	VPS7	VPS7a	VPS7	VPS7a	VPS7	VPS7a	VPS7	VPS7a	VPS7	VPS7a	VPS7	VPS7a	VPS7	VPS7a
CS-0.2.1	1.95	0.32	1.29	0.46		100	3.41	1.77	1.39	0.84	99.1	100	100	100
CS-0.2.2	3.54	0.59	3.12	0.85		99.85	5	2.05	3.19	1.10	84.7	100	100	100
CS-0.2.3	35.2	0.91	20.3	1.28		98.05	36.7	2.38	20.3	1.49	7.6	99.49	98.5	100
CS-0.2.4	304	1.19	156	1.46		96.72	305	2.65	156	1.58	0.3	98.75	83.2	99.74
CS-0.4.1	0.77	0.21	1.32	0.45		80.54	2.66	1.74	2.49	0.96	18.6	80.52	19.6	80.56
CS-0.4.2	0.27	0.24	1.04	0.58		55.86	2.15	1.85	2.63	1.17	8.6	55.82	9	55.93
CS-0.4.3	0.35	0.26	1.64	0.67		47.81	2.85	1.91	2.83	1.21	8.5	47.81	8.9	49.52
CS-0.4.4	0.29	0.26	1.41	0.67		43.95	2.16	1.92	2.73	1.21	7.7	43.91	8	44.02
CS-0.5.1	1.8	0.26	2.35	0.51		99.98	3.29	1.73	2.45	0.87	95.8	99.98	99.9	100
CS-0.5.2	1.85	0.35	2.66	0.72		99.84	3.36	1.83	2.76	1.01	93.1	99.97	99.7	100
CS-0.5.3	3.1	0.65	4.17	1.22		98.42	4.6	2.15	4.2	1.41	83	99.42	98.6	99.92
CS-0.5.4	6.7	1.13	7.97	1.82		7.96	8.2	2.62	8	1.95	10.1	8.20	17.3	8.37

Table 16 Variation of VPS results

[88] Empty cells correspond to results that are not available.