VDL Mode 2 Measurement, Analysis and Simulation Campaign

Document information	
Contract Title	VDL Mode 2 Measurement, Analysis and Simulation Campaign
Contract Number	SJU/LC/0301
Project Manager	NATS
Deliverable Name	VDL Mode 2 Measurement, Analysis and Simulation Campaign - Final Report
Deliverable ID	D11
Edition	00.01.03
Template Version	03.00.00
Task contributors	
ELSA Consortium and Programme Partnership	

Abstract

Two batches of investigations, measurements and simulations comprised of data from more than 400 revenue and measurement flights, analysis of 3 million air/ground exchanges, 700 hours of simulation representing 350,000 flight hours, and stress testing of common avionics configurations requiring about 50 days of cumulated live sessions have been conducted. Together with several workgroup sessions, and special investigations into possible protocol optimisations, MF deployment options and technical details for MF network operation, they provided a wealth of observations and findings. These form the foundation for a set of concrete recommendations for improving the performance and robustness of the data link deployment based on the current regulation and implementation rule, and also for the next phases of data link deployment. Improvements seen during the execution of the programme, as well as simulations of scenarios, confirm that performance can be brought to an acceptable operational level even in the short term assuming continued engagement and contributions from all stakeholders.

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SJU/LC/0109-CFT – D1602
VDL Mode 2 Measurement, Analysis and Simulation Campaign

Deliverable D11 – Final Report
Issue 1.3

ELSA Consortium and Programme Partnership

ELSA Final Report (D11) Consortium Sign-off

Organisation	SG Member Name	SG Member Sign-off	Date
Altys	Alexandre Simonin		
AIRBUS	Jerome Condis		
Arinc	Ty Robertshaw		
ENAV	Cristiano Cantoni		
Honeywell	Joeri De Ruytter		
Leonardo	Paolo Troyer		
NATS	Bob Broome		
Rockwell-Collins	Bertrand Chaigneau		
SITA	Francois Bardin		

DOCUMENT CHARACTERISTICS

Document Information	
Title	Final Report
Issue	1
Revision	3
Document reference ID	Deliverable D11
Security classification	Cleared Version

Document Authors and Authorisation		
Document Responsible	Andreas Kanstein (Telespazio VEGA)	
Contributors	Jean-Loup Rondeau (AIRBUS), Gianguido Bragagnini (ENAV), Kanaan Abdo (ALTYS), Dinesh Gogna (NATS), and ELSA partners.	
Reviewed by	Peter Whysall (NATS), Martin Karch (Telespazio VEGA), and ELSA partners/stakeholders.	
Released by	Dinesh Gogna (NATS)	Date: 30/06/2016

Document History				
Issue	Revision	Date	Modified Contents	Implemented by
0	1	13/05/2016	First draft released to ELSA partners	Andreas Kanstein
0	2	17/05/2016	Second draft released to ELSA partners and SJU	Andreas Kanstein
0	3	23/05/2016	Third draft released for internal review	Andreas Kanstein
0	4	30/05/2016	Fourth draft released for consolidation of comments	Andreas Kanstein
0	5	03/06/2016	Final draft – for external review	Andreas Kanstein
0	6	10/06/2016	Revised final draft	Andreas Kanstein
1	0	19/06/2016	First Release	Andreas Kanstein
1	1	21/06/2016	Updated after ELSA consortium feedback	Andreas Kanstein
1	2	28/06/2016	Updated after SJU feedback	Andreas Kanstein
1	3	30/06/2016	Formatting Updates	Andreas Kanstein

Executive Summary

In order to investigate evident Controller/Pilot Data Link Communications (CPDLC) performance issues, the Enhanced Large Scale ATN deployment (ELSA) consortium and programme partnership brought together 20 companies from across the industry: Air Navigation Service Providers (ANSPs), air/ground Communication Service Providers (CSPs), avionics and aircraft manufacturers, ground and airborne aviation communication system manufacturers, and companies specializing in test equipment and testing. Several airlines and EUROCONTROL provided data to support the activity.

Two batches of investigations, measurements and simulations comprised of more than 400 revenue and measurement flights, analysis of 3 million air/ground exchanges, 700 hours of simulation representing 350,000 flight hours, and stress testing of common avionics configurations requiring about 50 days of cumulated live sessions have been conducted. Together with several workgroup sessions, and special investigations into possible protocol optimisations, MF deployment options and technical details for MF network operation, they provided a wealth of observations and findings. These form the foundation for a set of concrete recommendations for improving the performance and robustness of the data link deployment based on the current regulation and implementation rule, and also for the next phases of data link deployment. Improvements seen during the execution of the programme, as well as simulations of scenarios, confirm that performance can be brought to an acceptable operational level even in the short term assuming continued engagement and contributions from all stakeholders.

Controller/Pilot Data Link Communications (CPDLC) is considered to be an important component of the evolution of Air Traffic Control. The development of data link in Europe was coordinated within the EUROCONTROL LINK 2000+ programme [2], and the CPDLC definition is based on the Aeronautical Telecommunication Network (ATN)[1] over Very High Frequency (VHF) Data Link Mode 2 (VDL2). The ATN/VDL2 communication infrastructure also provides support for the Aircraft Communications Addressing and Reporting System (ACARS), which is used for airlines' operational communication.

The expected benefit is an increase in sector capacity [3] [4], resulting in cost reductions and capacity gains for future traffic growth. In addition, data link is an important enabling component for many operational improvements coming out of the Single European Sky ATM Research (SESAR) programme [17].

However, ATN/VDL2 implementation design and subsequent deployment decisions in response to the Data Link Services (DLS) Regulation (EC) No 29/2009 resulted in a system that does not provide the expected performance. The scope of the DLS Regulation is limited to CPDLC in en-route, giving room for interpretation for the overall system implementation. The clearest indication of underperformance of the system is a high rate of Provider Aborts. Provider Abort (PA) is the technical term used to characterise ATN disconnections generated at the communication network and link level. The specifications of the system require a PA rate of one disconnection or less per 100 hours to meet the expected level of performance. A PA is directly visible by the end users, more so than message latency. A high PA rate and long message latencies severely limit the usability of the overall system. The situation led to the amendment of the original DLS Regulation resulting in the Implementing Regulation (EU) 310/2015.

A continuous centralised recording, reporting, and analysis of selected issues is provided by the EUROCONTROL DLS Central Reporting Office (DLS-CRO) [2]. Good progress had been made over time in identifying and correcting specific issues, but the PA rate remained high.

Several initiatives to analyse the problems and determine improvements have been conducted already, and they have been summarised in the EASA Report [1] in 2014 in response to a European Commission request.

[1] Currently based on ATN B1 standards (EUROCAE/RTAC and ICAO), supported by ATN/OSI network technology (ICAO standards).

This comprehensive report indicates several interlinked problems, and provides a preliminary plan in form of concrete actions.

It had been recognised that only an in-depth, synchronised investigation would help identifying root causes for the problems of the data link system, especially the high rate of Provider Aborts. In addition, the implementation of a multi-frequency VDL2 network, as recommended in the EASA report, required further analysis of implementation options and technical details.

To support the continuous growth of air traffic, the required level of DLS performance has to be achieved in the short term as well as the medium/long term. There are not only important economic reasons, like leveraging the investments made for ATN B1 deployment in the domestic European airspace (most States have completed their investments and more than 4500 individual aircraft have been equipped), but also to build confidence in the data link infrastructure's ability to sustain the upcoming steps of the future ATM roadmap. Figure 1 shows the CPDLC usage (in hours) and PA rate (in number of PAs per 100hrs of usage) observed during the ELSA project lifetime by the DLS-CRO[2].

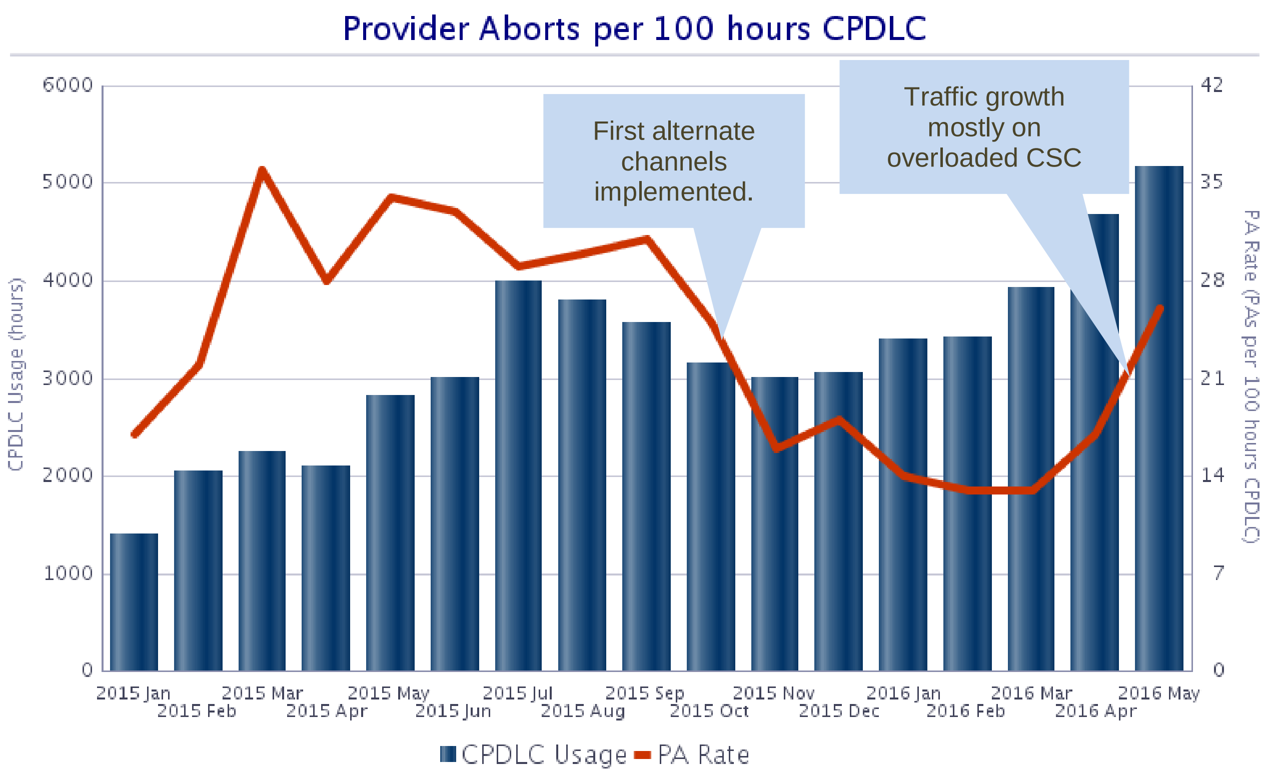

Figure 1 CPDLC Usage and PA Rate during ELSA project lifetime (from DLS-CRO).

The number of PA per 100 hours of CPDLC saw its peak with a value of 35 in March 2015, at a relatively low usage level (see Figure 1). It had decreased with the initial installation of alternate VDL channels; however rapid growth of CPDLC usage in the last months has caused the PA rate to rise again. Indeed, much of this traffic growth is occurring on the already overloaded first frequency, the Common Signalling Channel (CSC). While investigations are ongoing, preliminary observations lead to the following:

- The recent growth of CPDLC traffic appears to be dominated by aircraft operating avionics with known problems. Airlines have not yet had time to upgrade all of their aircraft avionics to the “best in class”. Alternate frequencies might not be usable by some of these configurations.

[2] Note that this should be at the level of the overall ATM Network but currently only Maastricht UAC, Skyguide, DFS and NATS are providing data.

- CSPs are in the process of network configuration changes to enable further MF deployments. This process temporarily reduces the availability of alternate frequencies.

Activities

The ELSA project has been conducted to provide this in-depth investigation into the technical issues of the current data link implementation, and into the multi-frequency deployment options, in order to restore the required level of performance. The DLS Regulation requires the provisioning of CPDLC service though ATN/VDL2 all over Europe above FL285. Nevertheless, in order to provide the service efficiently and to also provide AOC data link service through the same channels, ELSA considered the overall allocation of VHF Ground Stations (VGSs) to en-route, the airport area and to the CSC.

The project covered the following interlinked activities:

- A literature review conducted and discussed in study groups, providing important inputs to the revenue flight data analysis.
- Analyses of specific flight tests and revenue flight data collected on more than 400 commercial flights, where more than 7,750 CPDLC messages have been exchanged, representing 700 sessions and 300 hours of duration.
- Performance monitoring and analysis, for example, the April 2015 KPI analysis was based on more than 3 million air and ground exchanges.
- Systematic investigation of multi-frequency (MF) deployment aspects based upon Radio Frequency (RF) network architecture and channel allocation options, covering channel load management, RF network technical management, RF network topology, and CSP interoperability and coordination.
- Trade-off analysis of MF deployment options and technical details for MF network operation, and development of the associated deployment roadmap.
- Scenario building and simulations – based on VDL2 logs, network deployment, and topology details, as well as traffic and usage forecasts – about 700 hours of simulations have been run, corresponding to 350,000 hours of virtual flights and nearly 100 million of exchanged messages.
- Investigation of protocol adaptations that could improve overall system performance. From more than 30 proposed optimisations, 13 have been selected and improvements have been assessed and six have been found to provide benefits.
- Stressed interoperability and RF testing on a specific test bench with a number of certified avionics configurations – Communications Management Unit (CMU) and VHF Data Radio (VDR). Those interoperability tests required about 50 days of cumulated live sessions.

ELSA activities have been conducted in two waves, which allowed detecting issues in the first iteration and adjusting the analysis in the second iteration according to findings from the first, or, validating in the second wave the resolution of some issues identified in the first iteration. In parallel, studies, field tests and analyses have been conducted in the domain of the use of Multi-Frequency.

Further to the EASA report, ELSA has performed an in-depth investigation of the diverse technical topics characterising the use of more than one frequency (channel use, frequency assignment, VGS deployment etc.) and have identified a viable solution to the current performance issues of data-link communications - together with the method to achieve it.

Findings

The project confirmed that both MF deployment and resolution of technical issues as recommended in ELSA must be addressed to solve CPDLC performance issues. It is therefore important to consider all findings (from ELSA and previous initiatives) when investigating CPDLC performance issues, and to acknowledge that further initiatives and coordination is needed.

The general approach is: Alternate frequencies in VDL2 networks should be reserved frequencies, and there should be a single VDL2 network per Service area (areas homogeneous in terms of operational and technical needs, identical with FABs or new similar entities).

ELSA findings are presented as responses to recommended actions from the EASA report ([1] Section 6):

1. Ground Infrastructure

- The initial improvements at ground and air level that have been introduced and tested in the context of the ELSA project execution (e.g. early MF deployment, partial aircraft retrofit with upgraded avionics …) have proven to noticeably enhance the performance of the overall system.
- Simulations and log file analyses confirmed that today's VHF ground network deployment, which has been initially and mainly deployed to support Airline Operational Control (AOC) communications (for example, by placing a ground station at each terminal), was not deployed in an optimised way to support the Air Traffic Control (ATC) services. In some cases, there was excessive ground station coverage overlap, which increases collisions from hidden terminal transmissions. In other cases, there may have been areas of limited RF coverage, resulting from the incomplete deployment of the VDL ground station infrastructure, which created unexpected aircraft behaviours for the selection of ground stations. These situations were complicated by the lack of coordination between the CSPs that are sharing the CSC.
- Technical assessments of the various MF deployment options have concluded that the best model for MF deployment in Europe is a model where, comprising a number of Service areas, in which all ground stations operating on VDL frequencies in a given Service area work together under one unique frequency licensee responsible for managing the traffic on the RF network. This model allows the frequency licensee to manage the load balancing in a dynamic way (not to be confused with the concept of "dedicated" frequency model where frequencies are allocated in a static way).
- Technical assessments have shown that the following MF network topology and channel allocation aspects are important:
    - The use of reserved VDL2 alternate frequencies is preferred over the use of common VDL2 alternate frequencies, because they can be operated closer to the RF load threshold.
    - The addition of a fifth VDL2 frequency is preferred over the current four VDL2 frequency allocation in any network management approach.
    - The use of the CSC as a common command and control frequency shall be continued, but should be utilised for AOC/ATS data only in areas with low traffic levels.
    - In general, airport area and en-route datalink operations should be on separate frequencies in areas with high traffic levels. However, in areas with low to medium traffic levels, both airport area and en-route operations may be supported on a single frequency.
    - The deployment of VDL ground stations should be determined by the need to provide VDL2 en-route coverage, as requested by the DLS regulation. In addition, airport area coverage for initial logon procedures and for AOC traffic must also be provided.

2. Level of RF interference for the core European area

- The uncontrolled hidden transmitter effect (i.e., the uncoordinated ground transmitter activity due to overlapping intra- and inter-CSPs coverage, …) is the main contributor to the RF issues encountered during the project's lifetime, with a mean loss of more than 30% of the frames due to this type of RF interference. Additional interference can occur and the origin can vary from satellite signals to modulated voice, but those types of interferences represent less than 1% of the time.

3. Management of “hot spots”

- The saturation of the channel is confirmed with a Channel Use above 50% during peak hours over the core European air space.
- The current single frequency VGS deployment leads to areas with ineffective avionics’ handover behaviour (impacting the overall performance).
- Avionics suppliers shared the main principles for handover management. A detailed study was conducted by avionics partners in order to analyse the main reasons behind aircraft handovers. In congested areas (covered by many VGSs), or areas where there was a lack of coverage, the number of handovers increased dramatically for all avionics configurations. In addition, the interoperability tests identified differences between avionics implementations which led to various levels of performance in maintaining connectivity. These differences of implementation are driven by the flexibility of the guidelines defined in the current standards.

4. Concurrent management of AOC and ATN data traffic

- The sharing of channel usage between AOC and ATC contributes to the overall congestion of the frequency (mostly at the airport level), even though it is not the main contributor to the ATS problem.
- The current CPDLC traffic represents only a low percentage of the overall ATN traffic observed: the link maintenance constitutes significant overhead on the capacity usage. This ratio is nevertheless not at all representative of the nominal use of the CPDLC service (as of today, more than 4500 aircraft VDL2 equipped establish ATN connectivity with ground systems, while very few of them actually make operational use of CPDLC).

5. Management of air/ground communication service provision (distributed versus centralised)

- ELSA performed a technical analysis of the existing approaches to network management. Different ground RF network architectures can be described by a combination of three factors:
  - Number of different RF networks (operated by different providers) in the same Service area.
  - Type of frequency licensing (or allotment) used for the VDL2 channels.
  - Type of GSIF advertisement operated on each channel – with one-GSIF either ARINC or SITA is accepted, with two-GSIF both are accepted.

  A trade-off analysis has been conducted by considering the behaviour of the options, identifying which of them guarantees the best answer to the technical issues.
- The model ELSA determined as the best option for the multi-frequency network implementation is:
  - A single RF network is providing all VDL2 data link services in a Service area (areas homogeneous in terms of operational and technical needs, identical with FABs or new similar entities);
  - Alternate frequencies are reserved frequencies, licensed to only one operator in a Service area;
  - Two-GSIF channels are used, meaning all users can be accepted on the same network.

  Further technical solution aspects are described in D09 [7], for example load management (D09, Section 4.1.3) and interoperability between CSP networks (D09, Section 4.1.6). Network management details are provided in Annex F .
- In general, different network architectures, for example one RF network with two DSP IDs or two overlapping RF networks with one DSP ID per network, can be used during the transition phase to support VDL2 multi-frequency operations.
- A transition roadmap has been provided with three milestones defined as short, medium and long term from the current DLS implementation status to the identified target technical solution. These milestones have been identified according to the introduction of B1, B2 and B3 DLS as currently foreseen.

6. Avionics/ground end systems

- The project has identified “best in class” avionics configurations, which are considered as the set of airborne equipment necessary and sufficient to comply with the ATN/VDL2 performance expectations.
- The interoperability tests, with more than 500 variants of tests performed, showed that “best in class” avionics configurations passed the MF tests. The following additional results have been noted:
  - A few minor MF functionality issues without operational impact have been found.
  - Some MF interoperability improvements and clarifications for the relevant standards have been identified.
- Issues with ground sub-systems have been identified. Several of these issues have already been fixed during the project’s lifetime; others have been noted for a follow-up.
- Some flight crew operating procedures have suggested reset of the on-board equipment when facing CPDLC issues. This reset has proven many times to increase the instability of the link instead of solving the temporary issue.
- Several protocol optimisations were identified leading to capacity gain by reducing the number of messages exchanged:
  - The non-use of the routing protocol (i.e., IDRP) on the air/ground link could significantly reduce the volume of overhead traffic on the VDL2 channel and would remove some PAs caused by IDRP de-synchronisation. The IDRP protocol represents a very important part of the X25 traffic (~60% of X25 Data PDU).
  - The use of CPDLC LACK is mandated in Europe. When a TP4 frame is received, an AK-TDPU is sent before the CPDLC LACK. This implies the sending of 2 TPDU, leading to at least 2 AVLC PDU.
  - Most ACARS over AVLC (AOA) messages are acknowledged with an AOA General Response. This AOA message is generated by the ground network with a given latency. If this delay becomes higher than AVLC T2, an RR is generated by the AVLC protocol before the General Response. But, if this delay stays below T2, the AVLC acknowledgment is done with the AVLC INFO frame conveying the General Response.

Recommendations

Ground Network

- Improve the VHF Ground Station (VGS) network and fix the ground system issues (refer to 6.1 for details):
  - Use a dedicated channel for transmissions at the airport in regions with high traffic levels in en-route.
  - Use alternative communication means for AOC in the airport domain (e.g., Wi-Fi, cellular, AeroMACS) to off-load the frequencies used for CPDLC.
  - Progressively implement additional VDL2 frequencies in accordance with the traffic level.
  - Optimise the en-route VGS network coverage.
  - Ensure the availability of a fifth VDL2 frequency (at a minimum).
  - Use the CSC as common control channel only, unless traffic level is very low.
  - Implement ELSA recommended protocol optimisation: limit AVLC frame size.
  - Fix the ELSA identified ground system problems.
- Start implementing the transition roadmap to the MF VDL2 target technical solution: Introduction of alternate channels using reserved frequencies, addition of frequencies, and transition to one managed MF VDL2 network per Service area, see Annex E .

Avionics

- Harmonise avionics' performance, especially MF capability (refer to 6.2 for more details):
  - Upgrade of avionics to the "best in class" performance, showing no operational issues in the extensive validation described in Annex C , and supporting MF operations, especially FSL-based, GRAIHO and Autotune handovers.
  - Update flight crew operational procedures which had been introduced for older avionics, to avoid unnecessary avionics resets.

Standardisation and Compliance

- Define and implement an effective datalink end-to-end system certification process (including both ground and air components) and reference material for the ground network infrastructure (MOPS-like).
- Implement selected optimisations in future data link avionics systems (e.g. potential new ATN B1 builds, for instance for new aircraft types, or next generation ATN B2 data link systems) to enhance capacity usage:
  - Non-use of IDRP – progressively remove the IDRP usage on the airborne side.
  - Concatenate the CPDLC LACK (DTPDU) and the TP4 ACK in the same CLNP message.
- Include the selected interoperability improvements and clarifications in the relevant standards, and implement the resulting changes:
  - Handover algorithms: Align to improve reliability in maintaining connectivity. Also, handover algorithms could be enhanced based on guidelines identified in the simulation results, and this topic will be brought to the appropriate standardisation body.
  - Detect peer loss of communication: Clarify how to answer the situation when a loss of communication was observed due to exhaustion of uplink N2 retries with relation to expirations of the T1 retransmission timer (Uplink T1N2 situations).
  - Reduce ground ACARS latency (check/link with T2 AVLC).
- Include updates for MF interoperability (as identified in ELSA interoperability tests) in the relevant standards.

ATN/VDL2 Network Implementation and Oversight Framework

- Ensure a coordinated deployment and operation (see 6.4):
  - Establish/empower a pan-European air/ground datalink implementing function having appropriate steering responsibilities.
  - Establish/empower a pan-European ATN/VDL2 performance monitoring and spectrum coordination function.
  - Establish/empower a pan-European ATN/VDL2 end-to-end certification and oversight function for validating (ground and airborne) sub-systems acceptability.

Figure 2 provides an overview of the architecture of the foreseen target technical solution: One network is providing the ATN/VDL2 connectivity for all air/ground data link services.

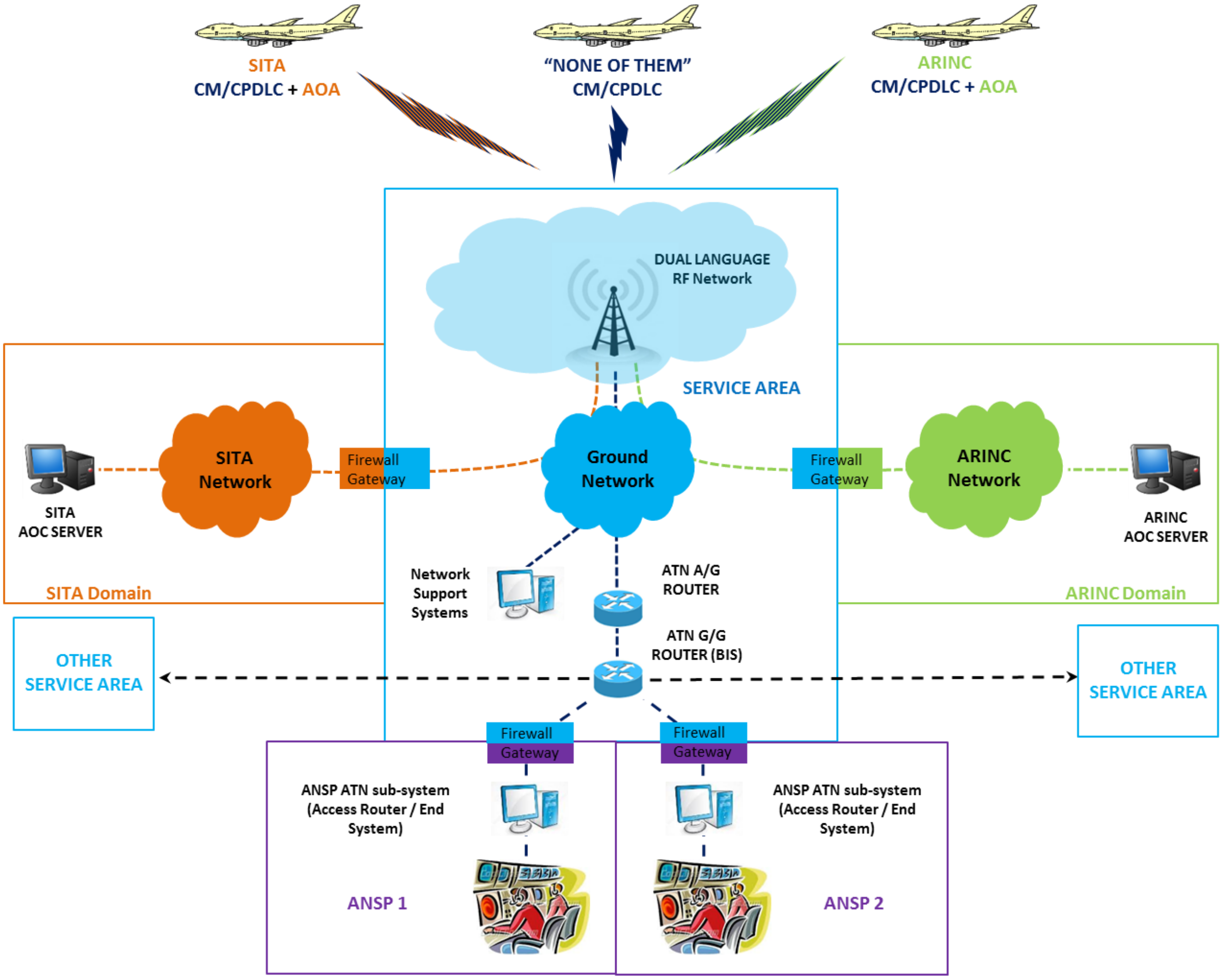

Figure 2 Target solution architecture overview (from D09)

ELSA simulations have shown that the current technology (ATN/VDL2) is viable for providing ATC communications in continental airspace and that performance should be acceptable if current technical issues and other inefficiencies linked to large scale deployment are adequately addressed. The simulation even of the current single channel deployment scenario shows that the technology is viable, but inefficiencies linked to large scale deployment have to be addressed. The work done in ELSA has generated a considerable amount of interesting data analyses, and has provided insight into the network conditions related to a number of PAs. In addition, it has identified a number of technical issues potentially impacting the VDL service performance. In a few cases, fixes were found and implemented over the course of the ELSA study. In several cases further consideration is required, especially when related to the optimisations.

The improvements already achieved from initial deployments (ground and air) of alternate frequencies support the recommendations made by ELSA.

The recommendations proposed for implementation will lead, if addressed in a coordinated way by all stakeholders, to an ATN/VDL2 system that provides acceptable performance to support the full deployment of ATN B1 CPDLC service in the European airspace. As an example, best in class avionics have demonstrated that they can provide less than 4 PAs per 100h CPDLC usage (compared to an average rate of 20 PAs per 100h of CPDLC as measured during ELSA project), without other ELSA recommendations being deployed. The recommendations proposed for implementation will furthermore provide sufficient

ATN/VDL2 capacity to support the deployment of ATS data link services in the European airspace until future generation network and communication means are available ((e.g. ATN/IPS, AeroMACS, future SATCOM and/or LDACS).

The VDL service performance will continue to improve as additional VDL ground stations and alternate frequencies are installed, and as CSPs transition to reserved frequency operations on the alternate frequencies. But, establishing a DLS with sufficient performance requires an increased level of coordination, including EU air transportation agencies, and serious attention to all ELSA recommendations.

Contents

1 Introduction

1.1 Context

This report presents the final consolidated results of the ELSA consortium and programme partnership activities, conducted between February 2015 and June 2016 on behalf of the SESAR Joint Undertaking under contract SJU-LC-0109-D1602.

It is recommended to consider the report as a whole, not just the concluding sections. Not all results are reflected in the recommendations but are captured in the findings, and the link to the recommended actions from the EASA report is also created through the findings.

Further detailed information can be found in the three technical documents on which this report is based: the VDL2 Performance Analysis [6], the Implementation Options for VDL Mode 2 Multi-Frequency [7], and the RF Analysis and Avionics Interoperability Tests [8].

1.2 Document Structure

The report is preceded by an Executive Summary, which is a complete overview of what is being presented in the text. Major results are also provided, however the recommendations cannot be summarised further than what is given in the respective Section in the main text.

This Section provides context information, document references, acronyms and definitions of important terms used. Section 2 provides the general problem statement and ELSA objectives, and links the project activities to the recommended actions of the EASA report [1]. The methodology for addressing the objectives is presented in Section 3.

Section 4 describes the findings, grouped by EASA actions. It also provides information on improvements that happened as a result of project activities. Section 5 provides the recommendations for improving data link to a level of satisfactory performance, and for the multi-frequency deployment steps. Finally, Section 6 provides an outlook to related activities.

1.3 References

[1] Technical issues in the implementation of Regulation (EC) No 29/2009 (Data Link), version 1.1, European Aviation Safety Agency (EASA), 23 April 2014.

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[17] SESAR Joint Undertaking, European ATM Master Plan, Ed. 2015.

1.4 Acronyms and Terminology

Acronyms used in this document are listed below.

Table 1 List of Acronyms

4D	4-dimensional
AEEC	Airlines Electronic Engineering Committee
A/C	Aircraft
ACARS	Aircraft Communications Addressing and Reporting System
ACSP	Air/Ground Communications Service Provider
ACK	Acknowledgement
AEEC	Airlines Electronics Engineering Committee
AFR	Air France
ANSP	Air Navigation Service Provider
AOA	ACARS over AVLC
AOC	Aeronautical Operational Communication
ATC	Air Traffic Control
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATSU	Air Traffic Services Unit
AVLC	Aviation VHF Link Control
BAW	British Airways
BRU	Brussels Airport, Brussels, Belgium
CDG	Charles de Gaulle International Airport, Paris, France
CLNP	Connectionless Network Protocol
CM	Context Management (used as CM/CPDLC)
CMU	Communications Management Unit
CPDLC	Controller/Pilot Data Link Communications
CRO	Central Reporting Office
CSC	Common Signalling Channel
CSMA	Carrier Sense Multiple Access
CSP	Communications Service Provider
CU	Channel Use (%)
CVME	Centralised VHF Management Entity

DISC	Disconnect
DLE	Data-Link Entity
DLK	Datalink
DLS	Datalink Service
DOV	Declaration of Verification
DSP	Datalink Service Provider
DM	Disconnected Mode
EASA	European Aviation Safety Agency
EC	European Commission
ELSA	Enhanced Large Scale ATN deployment
ENR	En-route
EZY	EasyJet
FANS	Future Air Navigation Systems
FEh	Binary pattern of 1111 1110 in Hexadecimal
FRA	Frankfurt am Main International Airport, Frankfurt-am-Main, Germany
FSL	Frequency Support List
GRAIHO	Ground Requested Air Initiated Hand-Off
GSIF	Ground Station Information Frames
HO	Hand-Over (or Handover)
HO_CMD	Hand-Over Command
HO_RSP	Hand-Over Response
ICAO	International Civil Aviation Organisation
ID	Identifier
IDRP	Inter Domain Routing Protocol
INFO	Information
ISH	Intermediate System Hello
KPI	Key Performance Indicator
LACK	Logical Acknowledgement
LE	Link Establishment
LE_RSP	Link Establishment Response
LCR	Link Communication Refuse
LHR	London Heathrow Airport, London, United Kingdom
MAC	Multiple Access (layer in the communication protocol stack)
MF	Multi-Frequency
MOON	System to monitor VHF transmissions
NSA	National Supervisory Authority
OSI	Open Systems Interconnection
PA	Provide Abort
PDU	Protocol Data Units
PECT	Peer Entity Contact Table
POA	Plain Old ACARS
RF	Radio Frequency
RR	Receive Ready
RSP	Response
RX	Receive
SARPS	Standards And Recommended Practices
SEL	Select
SESAR	Single European Sky ATM Research

SJU	SESAR Joint Undertaking
SNDCF	Subnetwork Dependent Convergence Function
SQP	Signal Quality Parameters
SREJ	Selective Reject
SUT	System Under Test
SVC	Switched Virtual Circuits
TOM	Thomson Airways
TP4	Transport Protocol class 4
APT	Terminal
TRTD	Technical Round Trip Delay
TX	Transmit
UA	Unnumbered Acknowledgement
VDL	VHF Digital Link
VDL2	VDL Mode 2
VDR	VHF Data Radios
VGC	VHF Ground Computer
VHF	Very High Frequency
VGS	VDL Ground Station
WA	Work Area
WBS	Work Breakdown Structure
XID	Exchange Identifier
XID_RSP_HO	Exchange Identification Response Handover
XID_RSP_LE	Exchange Identification Response Link Establishment
ZRH	Zürich Airport, Zürich, Switzerland

The following table lists definitions made by ELSA. It has been adapted from [7].

Table 2 Special Terminology

Alternate frequency	In the MF environment, a frequency (channel) other than the CSC.
Autotune	The capability of the ground system to command an aircraft to change from one data link channel to another by using a GRAIHO message, or the autotune parameter contained in uplinked responses to an LE or HO command message sent by an aircraft.
Common VDL frequency (channel)	Means that ground stations operating on that frequency in a given Service area are managed by more than one frequency licensee.
CSP	Any operator of VGSs is considered a CSP within the context of ELSA, including ANSPs that operate ATN/VDL2 ground infrastructure under a partnership model – under the assumption that the model is passing network management responsibilities to the ANSP.
Dual DSP ID System	All VGSs broadcast the IDs of multiple DSPs in its GSIF frames on the RF channel.
Dual squitter (dual language) system	Means that a single VGS will manage two GSIFs, usually applied for all VGS within an RF network.
Implementing function	The function of monitoring and steering the MF network implementation – see recommendation NetworkOversight-01.

Load balancing	At basic level, load balancing means ensuring traffic is equally distributed across channels with the same function (APT or ENR).
Load managing	Load managing is the capability of a RF operator to ensure both that a channel RF loading threshold is not exceeded and, if it happens, to rapidly reduce the loading on the channel.
Long term	Beyond 2025.
Medium term	Up to 2025 (expected introduction of ATN/B2 services).
One-GSIF channel	Means that all Aircraft (their avionics) will detect just a single DSP ID in the GSIF on a particular RF channel.
Reserved VDL frequency (channel)	Means that all ground stations operating on that VDL frequency in a given Service area work together under one unique frequency licensee responsible for managing the traffic on the RF network.
RF network operator	The entity in charge of operating on RF frequencies, usually the frequencies' licensee.
Service area	Portions of airspace, homogeneous in terms of operational and technical needs to provide data-link services in a safe, secure and efficient way. They could be identical with FABs or as new entities established regardless of state boundaries.
Short term	From today to 2018/2020 (respectively, deadlines for availability of the service and aircraft retrofit, according to the EU Regulation IR 310/2015).
Single DSP ID system	All VGSs broadcast the ID of only a single DSP in its GSIF frames on the RF channel.
Single squitter system	Means that a single VGS will manage one GSIF, usually applied for all VGS within an RF network.
Two-GSIF channel	Means that all Aircraft (their avionics) will detect two DSP IDs in the GSIFs on a particular RF channel.

2 Problem Statement

2.1 Introduction

The baseline for SESAR includes a data communications capability based on ATN/VDL2 which is expected to support the initial SESAR developed datalink services including Initial 4D.

In January 2009 the EC published the SES Data Link Services Implementing Rule (DLS IR) (EC Reg. 29/2009) which specifies European implementation dates of ATN/VDL2 and the associated first tranche of services.

As the use of VDL2 for CPDLC using ATN became more widespread, certain performance issues were observed that raised concerns on the usability of the system. Some of these issues were attributed to specific avionics installations for which solutions have been identified and corrected but other problems remained.

Under the mandate of the European Commission, late in 2013, EASA began an investigation into the observed performance issues of ATN/VDL2. The report was published in April 2014. The EASA report [1] highlights a 10-point Action Plan addressing actions including simulations, measurement campaigns, flight trials and deployment planning.

Following the report of EASA, the European Commission requested the SJU to analyse and prepare the inclusion of the EASA recommended actions in the SESAR Work Programme. Subsequently, the SJU raised a call for the collection and analysis of data from avionics and ground-systems. For this purpose, SESAR JU launched an open call for tender aimed at concluding a direct service contract with one successful tenderer to provide a VDL2 measurement, analysis, testing and simulation campaign.

2.2 Objective and Scope of SESAR JU Call

The activity defined within the SESAR JU call included the collection and analysis of data from avionics and ground-systems to determine the levels of RF interference and VDL2 channel occupancy as well as identifying issues affecting the end-to-end performance of the ATN/VDL2 datalink. The modelling and analysis of the options for multi-frequency VDL2 deployment, in particular the options for channel use, frequency assignment, network topology, and network management were to be assessed. It also included RF-level modelling of the VDL2 channel in support of both ATN and AOC communications.

A Consortium led by NATS and including eight other companies bid for the work. The proposal also included an extended partnership of eleven other companies and also had commitments from a number of airlines to assist with the data collection. The Consortium & Partnership named the project ELSA (Enhanced Large Scale ATN deployment). The ELSA Consortium was awarded the work and the Programme of work kicked off on 4th February 2015.

2.3 Description of Required Services under ELSA

The work to be performed under ELSA was described within four work areas (WA0-3) in the following sections.

2.3.1 Work Area 0: Project Management and Reporting

This work area was to consist of the project management of the activity and progress reporting to the SJU. Risks and issues management was also handled as part of this work area. This work area also consolidated all of the detailed technical analysis and reports from the other Work Areas into a final report (D11 – this report) which provides recommendations derived from findings resulting from addressing the action points of the EASA report referenced above.

Deliverables: A project plan, quarterly reports to the SJU and final project report including synthesis of the analysis and recommendations.

2.3.2 Work Area 1: VDL performance analysis

The main tasks and focus of this WA have been:

- Collection and analysis of data from avionics and ground-systems with the assessment of the severity of each problem to focus the effort on the most severe issues.
- Impact of the air-initiated handovers between ground stations.
- Determination of associated channel occupancy for ATC, AOC and the protocol itself.
- Determination of RF interference type, level and impact.
- A comparison of CPDLC exchanges in areas with varying AOC load as well as AOC datalink performance with ATC exchanges in the same environment.

The main objectives of WA1 have been:

- The completion of an in-depth analysis of the issues currently faced during the large-scale deployment of the ATN/VDL2 infrastructure in Europe;
- The proposal of associated solutions/recommendations prioritised according to their maturity and their cost/benefit characteristics.

WA1 analyses were based on data logs resulting from datalink capable aircraft operating in European airspace:

- Data logs resulting from test flights conducted before the project started. Some specific data logs contain both ground and aircraft traces;
- Data logs resulting from revenue flights (the major data contributor) conducted in the scope of the project. These specific data logs may contain both ground and aircraft traces;
- Data logs resulting from flight test campaigns conducted in parallel and outside the project.
- Analyses of specific flight tests and revenue flight data collected on more than 400 commercial flights, where more than 7,750 CPDLC messages have been exchanged, representing 700 sessions and 300 hours of duration.

Continuous monitoring of the ATN/VDL performance has been focused on

- Levels of RF interference and VDL2 channel occupancy;
- End-to-end performance figures including message timing and PA rates.

Deliverables: A draft (D03) and final report (D08) presenting the detailed VDL2 performance analysis as described above.

2.3.3 Work Area 2: Multi-frequency options modelling and testing

This work area was to consist of the modelling and analysis of the options for multi-frequency VDL2 deployment. In particular the options for channel use, frequency assignment, network topology, and network management were to be assessed.

The distribution of VHF ground stations (VGSs) was to be investigated according to the intended service coverage (airport surface, TMA, en-route). In a multi-link scenario this includes assignment of frequencies and the planning of transmission power. Performance of existing deployments which demonstrate different network approaches were to be taken into account.

This analysis was to be performed by taking into account the current AOC and ATN data traffic on one hand and the variations of aircraft traffic flows on the other hand. Simulations were expected to be performed for the distribution of all VGSs and their associated properties (emitting power, frequencies, etc.). The multi-frequency deployment roadmap produced by the EUROCONTROL Network Manager DLISG (Data Link Implementation Support Group) was to be taken into account (available on the EUROCONTROL DLISG One sky team page https://ost.EUROCONTROL.int/sites/DLISG/SitePages/Home.aspx). Multi-frequency scenarios were to be assessed with different schemes for frequency segregation assessed (geographical, dedicated airport frequency, segregation etc.) along with various options for utilisation of the commons signalling channel. Per ICAO SARPS the CSC was assumed to be used across the full VDL2 Service area and be used for data exchange if traffic volumes allow. The optimal usage of the available VDL2 channels, either as airport channel(s) to be used strictly on the ground at many airports or as en-route channels for delivering more CPDLC capacity, were to be considered. In scenarios where a specific frequency is assigned for airport use it would be important to characterise the AOC load associated with the airport environment.

There was to be a comparison between the air-initiated and the ground-requested air-initiated VGS handovers.

A technical trade-off analysis was to be conducted assessing the constraints and benefits arising from various existing models (e.g.: a distributed and/or subcontracted infrastructure (where intermediate communication providers provide part of the services) compared to a fully managed infrastructure. This was to include consideration of potential mechanisms for prioritisation of ATN messages over AOC messages managed by the ground station or network. The assessment was to derive the constraints to be imposed on the distributed constituents and on the governance processes in order to guarantee the expected performance for the network.

If feasible, flight testing of an initial multi-frequency trial implementation was to be performed as part of this work area.

This task was to result in a number of key outputs:

- Identification of implementation options for multi-frequency VDL2 with identified benefits and challenges
- Baseline for large scale validation of multi-frequency VDL2 in SESAR 2020

Deliverables: A draft and final report presenting the detailed VDL2 multi-frequency modelling and testing and network design and service model analysis as described above.

2.3.4 Work Area 3: RF level modelling and testing

This work area was to consist of modelling, analysis and testing at the RF level of the VDL2 channel performance.

Simulations and analyses were to be used to determine the optimum and limiting channel occupancy when concurrently managing both AOC and ATN protocols. This should include an analysis of protocol optimisation, assessing the trade-off between the use of long frames versus short frames (as for ACARS) and the use of multi-frame transmissions. The most appropriate frame transmission scheme to be used by Datalink Service providers and by ground systems were expected to be proposed. This should take account of previous work performed by EUROCONTROL in 2005-2008.

Multi-frequency interoperability testing of a representative set of avionics was to be conducted on a suitable test bench including with an appropriate interference background RF environment representative of the real measurements made in WA1. This testing was to be used to highlight interoperability issues in avionics implementations, feedback required updates or precisions required in the reference standards (ICAO Manual on VHF Digital Link (VDL) Mode 2 (Doc 9776). International Civil Aviation Organisation, EUROCAE ED-92B /

MOPS for an Airborne VDL Mode2 System operating in the frequency range 118-136,975 MHz) and validate the potential multi-frequency approach.

This task was to result in a number of key outputs:

- Report on the RF level analysis of VDL2 and the ATN protocols, estimation of the limiting channel load and recommendations as regards protocol optimisation
- Report on interoperability testing of avionics.

Deliverables: A draft (D06) and final report (D10) presenting the detailed VDL2 RF level modelling and testing as described above.

2.4 EASA Action Plan

This section lists the EASA Actions identified in the EASA Action Plan. Note that only six of the ten actions identified by EASA were relevant to the ELSA Program of work. However, all ten actions have been included here for completeness. The section also describes how ELSA has addressed the six actions directly and any impact to the other four actions. An overview of the six most relevant actions is provided in Table 1.

Table 3 EASA Actions [1] overview

EASA Action ID	Description
1	**Ground infrastructure**: The overall locations of VGSs should be designed according to the intended service coverage.
2	**Level of RF interferences for core European area**: A/C should be instrumented to analyse channel occupancy and RF interference level
3	**Management of “hot spots”**: The current zones/times …showing the highest AOC/ATN load should be identified. There should be a comparison of the limitations between the air-initiated and the ground-requested air-initiated VGS handovers.
4	**Concurrent management of AOC and ATN data traffic**: Determine the maximum channel occupancy when concurrently managing AOC and ATN. This should be performed with different frame lengths.
5	**Management of air/ground CSP versus distributed or centralised infrastructure**: Should establish how the control of the infrastructure could be performed in all cases.
6	**Avionics/ground end systems**: Avionics supporting multi-frequency should be trialled with instrumented installations.

The EASA report [1], Section 6, provides recommendations in form of a draft action plan. The following is repeating these actions and provides indications how these have been addressed with the ELSA activities.

2.4.1 **EASA Action 1: Location of VGSs**

The recommended activities were:

- An analysis of the placement and configuration of VHF Ground Stations (VGSs) with respect to the intended service coverage (considering airport surface, TMA, and en-route). The analysis should consider the current AOC and ATN data traffic as well as the variations of aircraft traffic flows.
- The simulation and limited deployment of an improved design, taking into account the existing infrastructure, by deploying a subset of VGSs and/or modifying some existing VGSs.
- The validation of the expected improvements with instrumented aircraft flying in the related areas, and the documentation of outcomes in support of decision making for wider deployment.

ELSA has addressed these through:

- An investigation of the current VGS positions in Europe.
- The identification of technical solutions able to ensure the intended service coverage (airport surface, TMA, en-route),
- The analysis of network logs in respect to the impact of the locations of VGS on the avionics HO behaviour.
- The analysis of ACSP logs in order to identify geographical zones where the probability of VDL2 connection failure is high (i.e. HO or LE retransmissions rate are high). These analyses allowed to geo-localize areas where the network coverage's were not optimized.

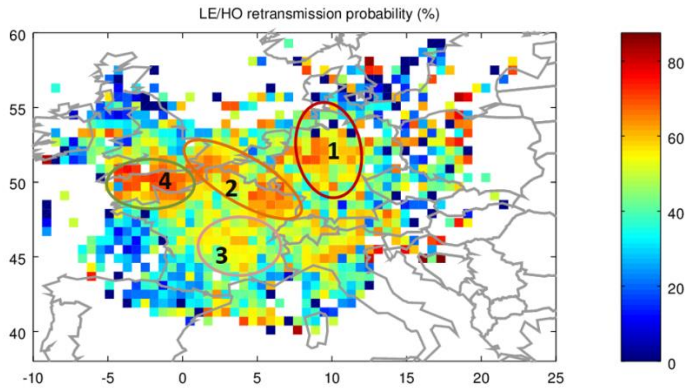


Figure 3 ARINC estimated HO failure probability (2 Apr. 2015) (from D10)

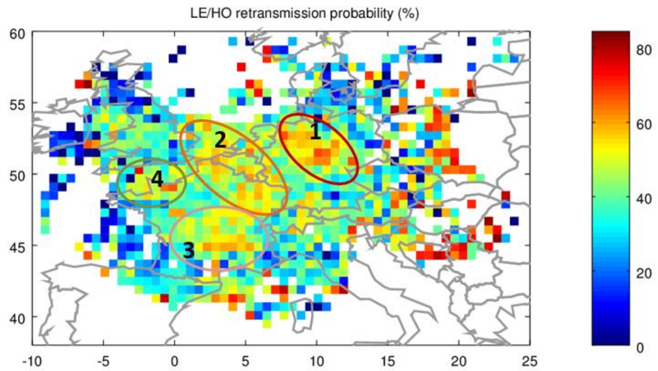


Figure 4 ARINC estimated HO failure probability (18 Dec. 2015) (from D10)

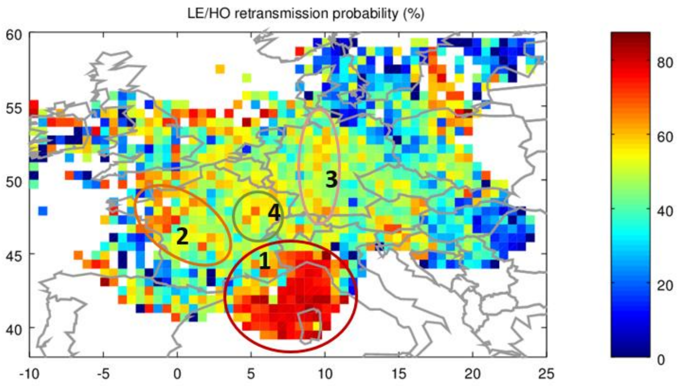


Figure 5 SITA estimated HO failure probability (18 Dec. 2015) (from D10)

The analysis (cf. Chapter 4 D10) has shown that:

- For both ACSPs, the retransmission probability is high over Europe (~50%).
- For both ACSPs, the area between London and Paris has a very high retransmission probability (~75%). These results were also confirmed by the simulation results, (cf. D10 2.4.6) where the simulated aircraft was not able to maintain the VDL2 link properly because of too many hidden ground stations and uplink collisions.

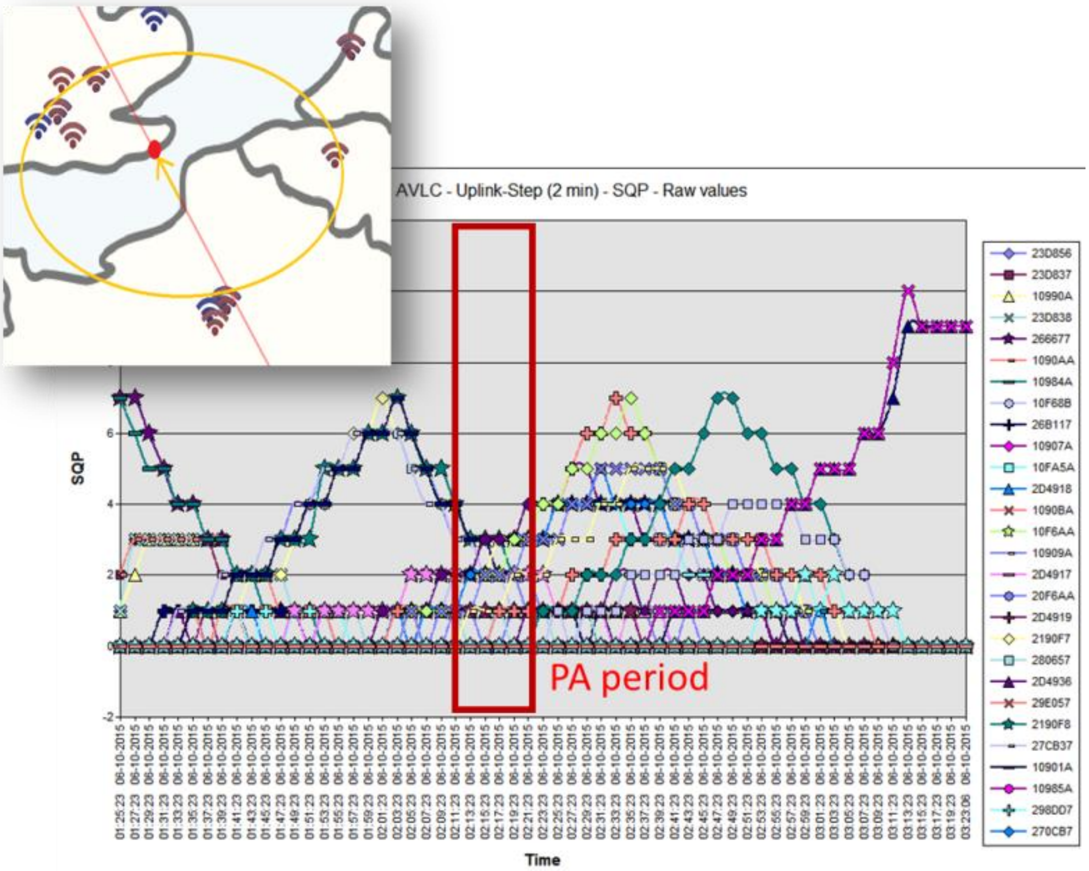


Figure 6 Hidden ground stations effect leading to PA, Paris/London flight (from D10)

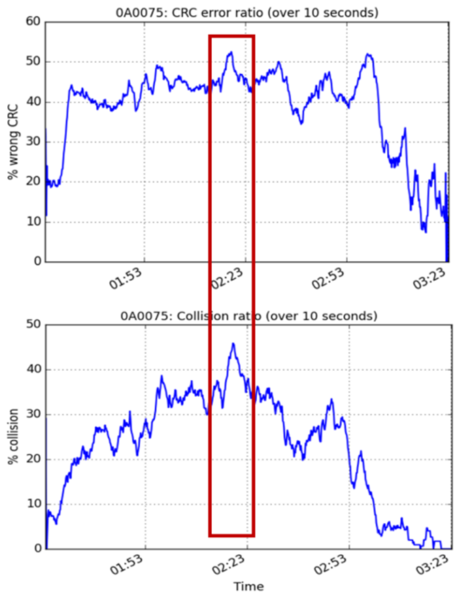


Figure 7 Collisions & erroneous frames rate during PA period (from D10)

- For SITA the area from Belgium to NE of France has a very high probability (~75%) due to incomplete network coverage

- The RF analysis has shown that some areas have a substantial probability of transmission failure (8% to 15% in the centre of France, 20% in the east of France). This probability represents only the failure probability, due to signal level. It does NOT reflect the message loss due to collision and high CU. This probability is also estimated from ground radio point of view and it depends on ground radio performance.

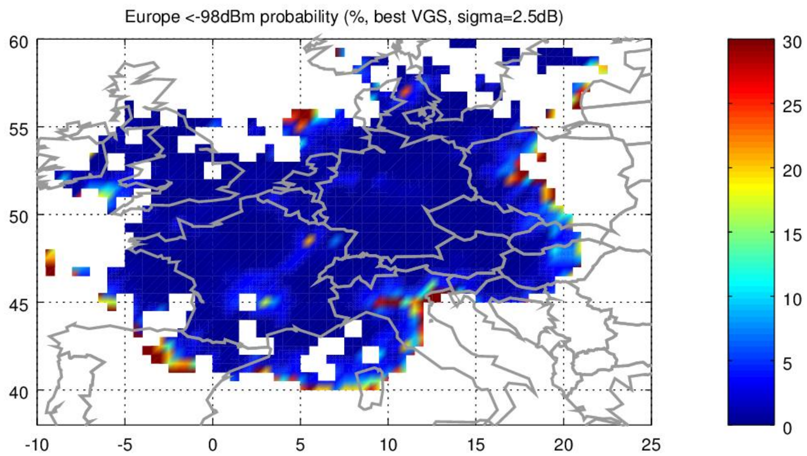


Figure 8 Europe signal <-98dBm probability (%, best VGS)

- The analysis of multi-frequency VDL2 deployment options, by means of flight trials, revenue flights in airspaces serviced with initial multi-frequency deployments and studies concerning various topics transversal to the different MF deployment options. Indications for an appropriate network design including the distribution of VGSs have been provided, and verified by means of simulation-based analysis, taking into account the currently deployed infrastructure.

- The simulation of the current deployed network confirmed that today's VHF ground network deployment to support AOC communications is not necessarily optimised for ATC services. In some cases, there was excessive ground station coverage overlap, which increases collisions from hidden terminal transmissions. In other cases, there were areas with limited RF coverage. These situations were the result of the incomplete deployment of VDL ground stations and alternate channels and were complicated by the need for CSPs to share VDL alternate frequencies.

- The definition of the technical solution for the long term ground RF network, and the definition of a complete transition roadmap starting from today's network situation.

2.4.2 EASA Action 2: Level of RF interference for core European area

The recommended activities were:

- Aircraft with avionics having a good record of satisfactory connections that are flying in the core European airspace should be instrumented and data collected.
- The data should be used to analyse channel occupancy and RF interference level. The outcome should be correlated with the CRO's problems database and investigations.

ELSA has addressed these through:

- Analysis of revenue flights data collection performed based on two batches of data. The selected equipages were equipped of the last available version.
- Additional test recordings and specific RF flight recordings have been collected from different sources (including results from a specific measurement campaign performed by EUROCONTROL), and data has been reviewed to drive conclusions.
- Performance monitoring, based on ground systems logs located in the core European airspace, including data on the channel use rate.

2.4.3 EASA Action 3: Management of "hot spots"

The recommended activities were:

- Identification of the times and airspace regions showing the highest AOC/ATN data load, and analysis whether the algorithms defined in the relevant technical standards are suitable.
- Development of a complementary proposal for the ground management of VGS ground-requested air-initiated handovers, prototyped and trialled. There should be a comparison of the limitations between the air-initiated and the ground-requested air-initiated VGS handovers.

ELSA has addressed these through:

The data collected though the ground logs collection and the MOON monitoring network [14] has been used to analyse and plot hand-over behaviours over extended core European airspace in relation with the VGS environment.

- Based on ground logs, the number of HO per aircraft per area has been plotted on a map, on a per CSP basis.
- ELSA simulations provided the possibility to match the PA distribution with the same kind of map.
- KPI monitoring gave the opportunity to understand the current impact of the HO on the channel capacity usage for the ENR.
- KPI monitoring and operational analysis allowed identifying if the last upgraded algorithms mechanisms have improved the situation.

  - With those activities, ELSA had been able to identify how the HO mechanism is impacted by the ground system deployment. In addition, ELSA had the capability to differentiate the "best in class" HO behaviour.

- ELSA took also into account that the current operational management of the handovers is either air-initiated or ground-initiated.

2.4.4 EASA Action 4: Concurrent management of AOC and ATN data traffic

The recommended activities were:

- Determination of the maximum channel occupancy when concurrently managing AOC and ATN protocols under the conditions of the intended use and with different frame lengths, using simulation-based analysis.
- Based on the results, the definition of a limitation to AOC traffic frame length to balance performances of both AOC and ATN data traffic. Potentially propose other network management techniques compatible with VDL2.

ELSA has addressed these through:

- Based on CSPs logs data collection, various KPIs have been defined to monitor the ratio of traffic including AOC and ATN both on the airport level and in en-route.
- In 2015, the AOA protocol is the main source of long AVLC frames. The side effect of transmitting long AVLC frames is the channel occupancy induced in case of retransmission, in addition to increasing of the probability of uplinks collisions. That's why very long AVLC frames should be avoided mainly when the overall channel occupancy is high. Consequently, an optimisation has been proposed and consisted on reducing the AOA frame size by reducing the AVLC N1 parameter to match the average ATN frame size while still allowing an AVLC frame to contain one AOA packet (i.e. one ACARS block). The proposed value for N1 is 251 bytes. Note that this optimisation is a short term answer that has to be reconsidered in the future with the deployment of the ATN Baseline 2, when long ATN messages are expected to come.
- In order to answer the long term horizon, the ATN/AOA prioritizing at ground side has been also studied as another optimisation topic and assessments have been performed through simulations and analysis. The main outcome is that an aircraft doing ATC communication could be affected by vicinity doing AOC. In other terms, an aircraft doing long AOA messages could negativity impact the performance of the surrounding aircraft, as illustrated in the figure below when no QOS exists.

In order to avoid such a situation, it is required to avoid overlapping between AOA and ATN ATC on the temporal resources by applying basic QoS rules. This will allows a secure and seamless segregation of the data paths as so to avoid network congestion.

For the QoS rules, it is required to segregate data by at least two things: one is by its importance, and the other is by its volume. As a general rule, important data typically is not high volume; it is low volume. QOS rules definition for ATC & AOC sharing (over the VDL2 channel) have to be clarified and to be followed-up by the standardisation groups.

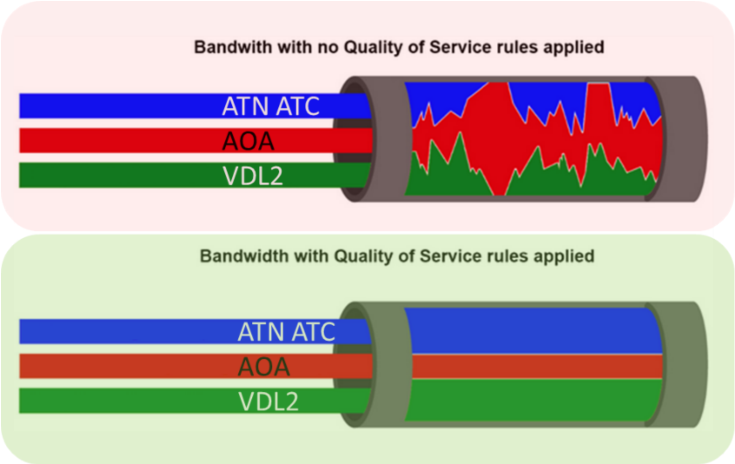


Figure 9 Bandwidth with no QoS applied vs. QoS applied (from D10)

2.4.5 EASA Action 5: Management of air/ground CSP

The recommended activities were:

- A technical trade-off analysis of the constraints and benefits arising from different models for the service provision, from a distributed infrastructure (where intermediate providers such as ARINC or SITA provide some services) compared to a fully managed infrastructure (where the CSP is completely in charge of its network) up to a fully centralised model.
- The assessment should provide the constraints to be imposed on the distributed constituents and on the governance processes which are needed to guarantee the expected performance for the network, and should establish a complete model for the control of the infrastructure.

ELSA has addressed these through:

- The investigation of three different models for managing the DLS provision:
  - Service model (infrastructure fully managed by CSPs);
  - Partnership model (CSPS and ANSPs cooperate for AOC and ATN services);
  - Development model (infrastructure owned and operated by ANSPs).
- A proposal for the most suitable multi-frequency infrastructure deployment (identified as target MF deployment solution) has been developed in form of a technical study. Multi-frequency scenarios for 2025 and beyond which model related options have been simulated and analysed.
- The technical study and the simulation of the multi-frequency deployment scenarios included initial infrastructure control policies.

2.4.6 EASA Action 6: Avionics/ground end systems

The recommended activities were:

- Avionics supporting multi-frequency should be trialled with instrumented installations to gather data related to the channel technical usage. The data collection and subsequent analysis should enable the characterisation of the effect of multi frequency on the different protocol layers.

- Installed configurations currently showing a high level of disconnects should be assessed in a multi-frequency environment, if capable to operate therein. If problems persist, such installations should be instrumented in order to determine the causes of the problems.
- For avionics which generate internal failures or resets of connected units, EASA is obliged to act if there are safety concerns. However, reports would be needed in order to be able to justify the issuance of the appropriate corrective action.
- EASA could potentially undertake a dedicated audit of the airborne parts and appliances that have already been certified to assess continuing compliance with the declared certification basis. Further, the NSAs (National Supervisory Authority) could undertake a review the Declaration of Verification (DOVs) issued by their ANSPs.

ELSA has addressed these through:

- Interoperability tests were executed with different representative avionics systems provided and operated by AIRBUS, Rockwell-Collins and Honeywell (cf. section 6 in D10).
- The interoperability tests activity performed between representative avionics benches and the test platform allowed to test a wide scope of functions on the avionics side – starting from the lowest physical layer with the VDR RF tests, the VDL2 MF tests in a representative environment and scenarios, virtual flight tests and ending by end-to-end CPDLC tests.
- VDL2 MF tests based on the “EUROCONTROL VDL2-MF test cases” document covering all the VDL2 MF methodologies have been performed: FSL (Frequency Support List, air and ground), GRAIHO (Ground Requested Air Initiated Handover), Auto-tune commands included in LE and HO responses, Air-ground transition (FSL-based), Ground-air transition (FSL-based).
- The overall tests results of the different avionics configuration showed a good support of the tested baseline for the different VDL2 MF mechanisms. Only some minor non-conformity issues were identified not impacting operational deployment

Flight trials have been performed to test the identified multi-frequency options.

- Additional data has been recorded by ground in airspaces serviced with initial multi-frequency deployments with instrumented aircraft. This data has been used to test the suitability of the avionics for the deployed multi-frequency configurations.
- The analysis of data collected with instrumented aircraft, the results of the laboratory testing, as well as the analysis of ground recordings conducted by ELSA provide information about conformance with applicable standards.

The remaining actions have not been considered in the main scope of ELSA, but some activities and findings support these actions:

- Coordinate through standardisation bodies’ clarifications and/or additional requirements as described in section 6.8.2 in D10 for the MF identified recommendations.

2.4.7 EASA Action 7: CSP performance monitoring

The recommended activities were:

- This action should assess the status of the process, the metrics and the tools already developed by CRO/CSPs and their adequacy to assess network performance and the CSP services in general. It should propose modifications or new developments suitable to continuously monitor the criteria alerting on a necessary activity before the degradation of the overall network below the required performance. This analysis should take into account the way that the CSPs provide services both for AOC and ATN traffic over the same channel(s).

ELSA has addressed this through:

- This was not considered in the scope of ELSA. However, based on the findings a recommendation has been phrased to request that an independent function to assume monitoring and steering responsibilities is established.

2.4.8 EASA Action 8: ground/ground network

The recommended activities were:

- This action shall develop or reuse the process, criteria and tools in order to monitor and act upon ground infrastructure bottlenecks.

ELSA has addressed this through:

- This was not considered in the scope of ELSA.

2.4.9 EASA Action 9: CM/CPDLC interoperability robustness testing

The recommended activities were:

- The test benches have been an excellent tool to debug the interoperability requirements of avionics and ground data link end systems. This action should continue to sponsor interoperability testing with any of the existing test benches for any new or modified product. This would avoid adding problems at network level, that could have been identified and that would be much harder to isolate in the network or during operation.
- Additionally, this action should install automated CM/CPDLC exchanges between selected end ground system and avionics in multi-frequency environment. The objective would be to assess pre-defined scenarios as well as robustness to high load.

ELSA has addressed this through:

- Interoperability testing has been conducted on avionics datalink components only, including testing of functionality needed for the multi-frequency environment.

2.4.10 EASA Action 10: ground data link end systems

The recommended activities were:

- In addition to Action 9 for new deployments of ground data link end systems, this action shall elaborate a comprehensive deployment package based on the technical standards and on the specific aspects of the European infrastructure. It would allow a harmonised verification, acceptance and introduction into service process of the end systems by the ANSPs (involving the respective Competent Authorities). It shall contain requirements, explanations on infrastructure decisions as well as recommendations explaining the rationale.

ELSA has addressed this through:

- This was not considered in the scope of ELSA, but findings reinforce the needs for such processes.

The following Section presents the ELSA methodology, followed by the Section presenting activities (data collection, measurements and simulations) and resulting findings and conclusions in the context of the EASA actions.

3 Methodology

The methodology description has been structured to follow the organisation of the ELSA project in Work Areas, which are

- WA1: Collection and analysis of data from avionics and ground systems to determine the levels of RF interference and VDL2 channel occupancy as well as identifying issues affecting the end-to-end performance of the VDL2 datalink, the ATN network, and the B1 applications [6];
- WA2: Modelling and analysis of the options for multi-frequency VDL2 deployment, in particular the options for channel use, frequency assignment, network topology and network management [7];
- WA3: RF-level modelling of the VDL2 channel in support of both ATC and AOC communications and avionics' interoperability testing [8].

3.1 Literature Review, Data Collection and Performance Monitoring

WA1 activities have been divided into three domains. The purpose of this split was to use three different views to better assess the hotspots of the maturity issues.

- **Literature review**

The existing knowledge about VDL2 maturity issues is spread among many entities. The scope of the literature review was to collect available papers, studies and tests dealing with ATN/VDL2 Data Link communication issues in order to consider the outcomes from all previous studies and recommendations. As an output of this activity, some recommendations on scenarios, data recordings and analyses were proposed.

The aim of this domain was to summarise the main problems observed in the ATN/VDL2 Data Link communications from the literature available today and documented by former studies. The additional intention was also to identify areas which had not yet been tested or situations where data might have previously been unavailable.

- **Revenue flight & test flights data collection**

For the first time, WA1 provided an opportunity for all aviation stakeholders to collaborate in analyses, supported by software tools. The revenue flight data collection enabled the identification of the most important issues and facilitated focusing on the main ones. The literature review was also a necessary input to the overall analysis.

This data collection has been divided into two batches. The first batch has enabled, in association with the literature review, accentuation of the main maturity problems. The second batch enabled a further step from the collection of more data and also permitted a deep-dive on the main topics to understand/solve.

- **Performance monitoring**

The collection of VGS logs has enabled the creation of a very large and comprehensive set of KPIs. The methodology did not foresee limitation of the analysis to the known performance parameters (e.g., PA rates reported by EUROCONTROL), but to isolate some particular behaviours on various sets of KPIs. Once the particular behaviours were isolated, it was easier to identify the possible impact on the performance and the potential associated improvement.

The general WA1 methodology has been to maximise the cross-feed between the three sources of data. The findings were checked across these multiple sources.

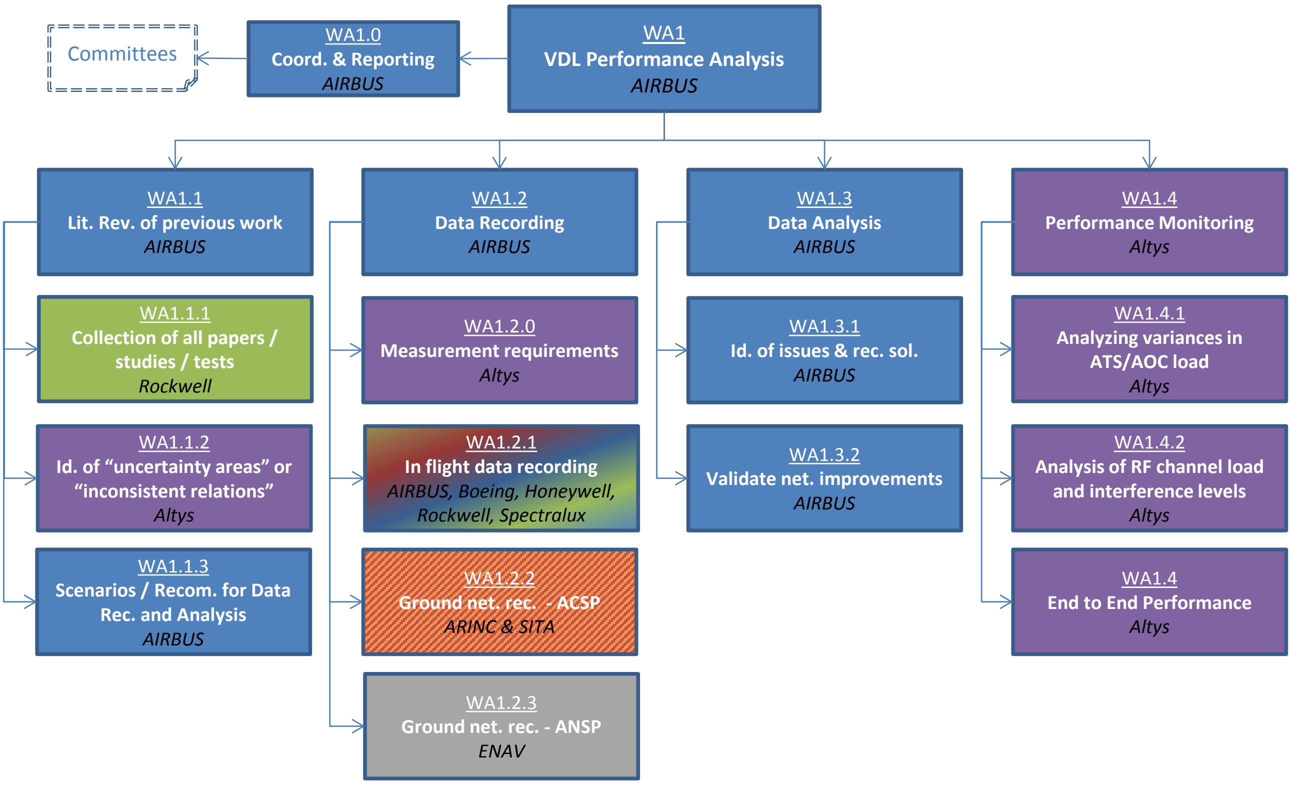


Figure 10 WA 1 Organisation (from D08)

3.2 VDL2 Multi-Frequency Modelling

3.2.1 General Aspects

WA2 has conducted a technical analysis of the possibilities and trade-offs for VDL2 multi-frequency deployment. The following items need to be considered in order to clarify the methodology used:

Objective: the objective of WA2 was to identify the technical solution suitable to implement the Multi-Frequency VDL2 over Europe.

Principles: two principles have been identified as essential in approaching the task of WA2:

- The request for providing realistic solutions to concrete issues in deploying Multi-Frequency VDL2 requires considering which options can realistically be implemented. In practice, this means that when studying how to implement the MF VDL2 system in Europe, the "from scratch" approach has been considered as a possibility for the long term.
- The need to develop the technical solution by a top-down approach.

The first of these two items determined also the inputs to be considered as a starting point: They consist of what is currently implemented in the DLS framework in terms of both technical and institutional aspects.

Inputs: according to the objectives and principles described above, the inputs considered as starting points were:

- original scenario (ELSA start - Feb 2015):
    - Current ICAO FMG allotment plan (four common frequencies)
    - SJU Capacity Study (four common frequencies)
    - Already deployed MF VDL2 RF networks
    - Available MF technologies

- first MF scenario (formally considered in ELSA from Sept 2015):
    - Draft ICAO FMG allotment plan (dual squitter systems with five frequencies where alternate frequencies are reserved)

3.2.2 Stepwise Process

The work done in WA2 followed the sequence of six steps listed below:

STEP 1: Definitions and WA2 leading points

In ELSA WA2, perhaps for the first time, different operators using VDL2, each one with different roles and visions, have met to assess a harmonised way to deploy the same services across Europe, in an efficient and safe way.

In order to have clear and aligned understanding the first step was to agree the definitions in order to have a common basis for WA2 technical discussions.

In the same way, the WA2 partners established some common points in order to develop a strategy to perform their activities. These were based on some “WA2 leading points” concepts to take as a reference.

The definitions are listed in D09 Section 3.2.1, the WA2 leading points are reported in D09 Section 3.2.2.

STEP 2: Technical analysis

Seven technical aspects were identified that were to be addressed in order to study the expected behaviour of the systems implementing the identified technical options, and to evaluate their suitability in meeting MF VDL2 implementation needs. These were:

- RF Network architecture
- Channel allocation
- Load balancing and management
- RF Network technical management
- Frequency function assignment
- RF Network topology (VGSs distribution)
- CSP interoperability and coordination

The detailed technical analysis is reported in D09 Section 4.1.

STEP 3: Field analysis

In order to have the most complete vision possible of the technical aspects of MF deployment, a collection (also in cooperation with the other WAs) and analysis of “on field” data has been performed (D09 Section 4.2).

In particular, the analysis was performed of the information obtained from:

- Data from revenue flights operated by the already deployed RF networks (with two frequencies) from :
    - ARINC
    - SITA
    - Skyguide

- Data from flight trials operated by ENAV (with three frequencies):
    - ENAV Flight Inspection Dept

- Italian Air Force – “31st Stormo”

These have provided inputs for the following points:

- MF Performance evaluation on the VDL alternate frequencies and CSC unload.
- Frequency management evaluation using both FSL and Autotune techniques to move aircraft between the CSC and VDL alternate frequencies
- Frequency function evaluation with the use of separate frequencies for APT and ENR operations.

STEP 4: Identification of the possible “Technical Options” suitable to implement MF VDL2

Performing the analysis of the Technical Indicators, it became clear that the MF VDL2 deployment involves a number of interconnected aspects. Therefore, WA2 partners identified the need to synthesize all the information collected in a well-defined base-line from which to develop research of the technical solutions. The information collected covered different aspects such as frequency availability, capacity, technologies, frequency management, etc.

On this basis, the fourth step was dedicated to identify the possible technical “options” (considered in relation to the base-line) suitable to implement the MF VDL2 (D09 Section 3.5).

This approach had two aims:

- To perform the trade-off analysis over the list of the technical “options” in order to identify the Technical Target Solution to implement the MF VDL2 in long term (Step 5 – D09, 4.1).
- To provide a first assessment for the possible approach to short term MF deployment by taking into account the identified “options” (Step 6 – D09, 4.2).

STEP 5: Identification of the “Technical Target Solution”

The fifth step constitutes the core of the WA2 activities because it consists of the trade-off analysis (D09, 4.1). The objective for this was to compare the expected performances of the different technical options in order to establish which of these is the better option to meet the requirements for the deployment of MF VDL2.

So, at the end of Step 5, the “Technical Target Solution” for long term is provided in terms of:

- The description of the RF network architecture
- The definition of the channel allocation
- The identification of the MF technology suitable to implement the technical solution
- Further identified findings on technical aspects

STEP 6: Drawing of the transition roadmap from the current overall situation to the “Technical Target Solution” implementation

The implementation of the identified Target solution is a matter for the long term. The transition from the current situation to the target solution shall be carefully addressed as it has to perform the best compromise between efficiency and safety.

The sixth step is dedicated to address the Transition Roadmap (D09, 4.2). The timeframe from today to 2030 has been considered, identifying three milestones (2018/2020, 2025, beyond 2025) as reference steps for the transition.

3.3 VDL2 RF Level Analysis and Avionics Interoperability Test Activities

In order to describe the methodology used, the objectives of WA3 needed to be defined first:

- Protocol optimisation: to explore potential adaptations to the applicable standards and assess their potential benefits on overall system performance, while minimizing changes to existing implementations.
- Stress COTS avionics (i.e. that are certified according to applicable standards[3]) and assess their multi-frequency operations when placed in a representative European airspace.

To reach these objectives, the following activities were performed:

- Investigation, through simulations and analyses, of protocol adaptations that may improve overall system performance:
  - Parameter change (timers, counters).
  - Modified and/or new features.
- Interoperability and radio frequency (RF) testing with a number of certified avionics configurations (CMU+VDR) to assess stability and to measure performances when operated in a representative RF environment.

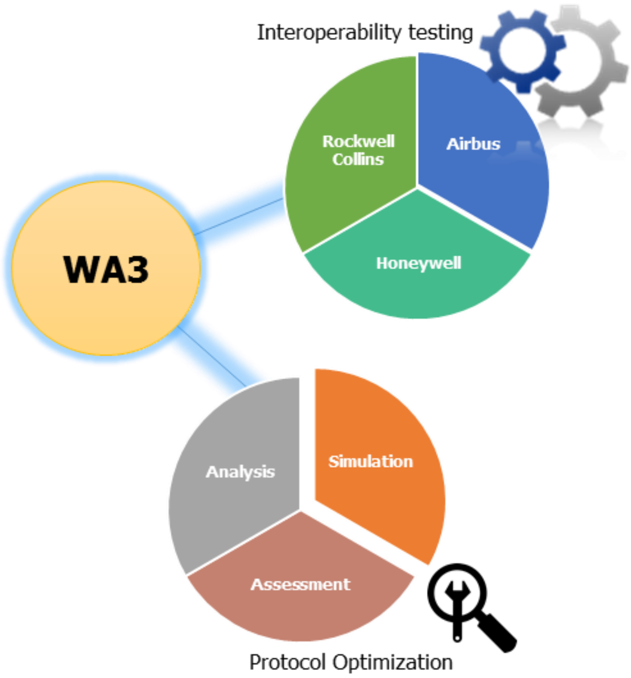


Figure 11 WA3 activities overview (from D10)

The WA3 included the following sub-activities:

- WA3.1: the objective was to define reference scenarios, build the platform and baseline the results to be used for WA3.2 and WA3.3.
- WA3.2: the objective was to evaluate optimum/limiting VDL2 channel occupancy by tweaking protocol parameters through simulations and analyses, and recommend updates to standards when applicable.

[3] RTCA DO-178B, European Commission requirements and the applicable protocol standards (ARINC, EUROCAE, ICAO and SARPS)

- WA3.3: the objective was to verify avionics VDL2/ATN/MF interoperability in a representative RF/VDL2 environment, by simulating a typical flight over European airspace, and to validate multi-frequency approaches.

The WA3 activities were organised in two iterations:

- The first iteration included one main scenario based on a typical day identified in April 2015. This scenario was used for protocol optimisations and for interoperability tests with avionics.
- The second iteration included different scenarios taking into account multi-frequency deployment strategies identified within WA2 (i.e. common frequencies, reserved frequencies) and alternate dedicated scenarios. These scenarios were built based on a second typical day in 2015 (December and April), and forecasted periods 2018, 2025. The forecasted scenarios were built based on EUROCONTROL STATFOR forecasts while comparing to the SESAR VDL2 capacity study [12]. These scenarios were also used for the second batch of interoperability tests with the avionics which were covering mainly the multi-frequency scope.

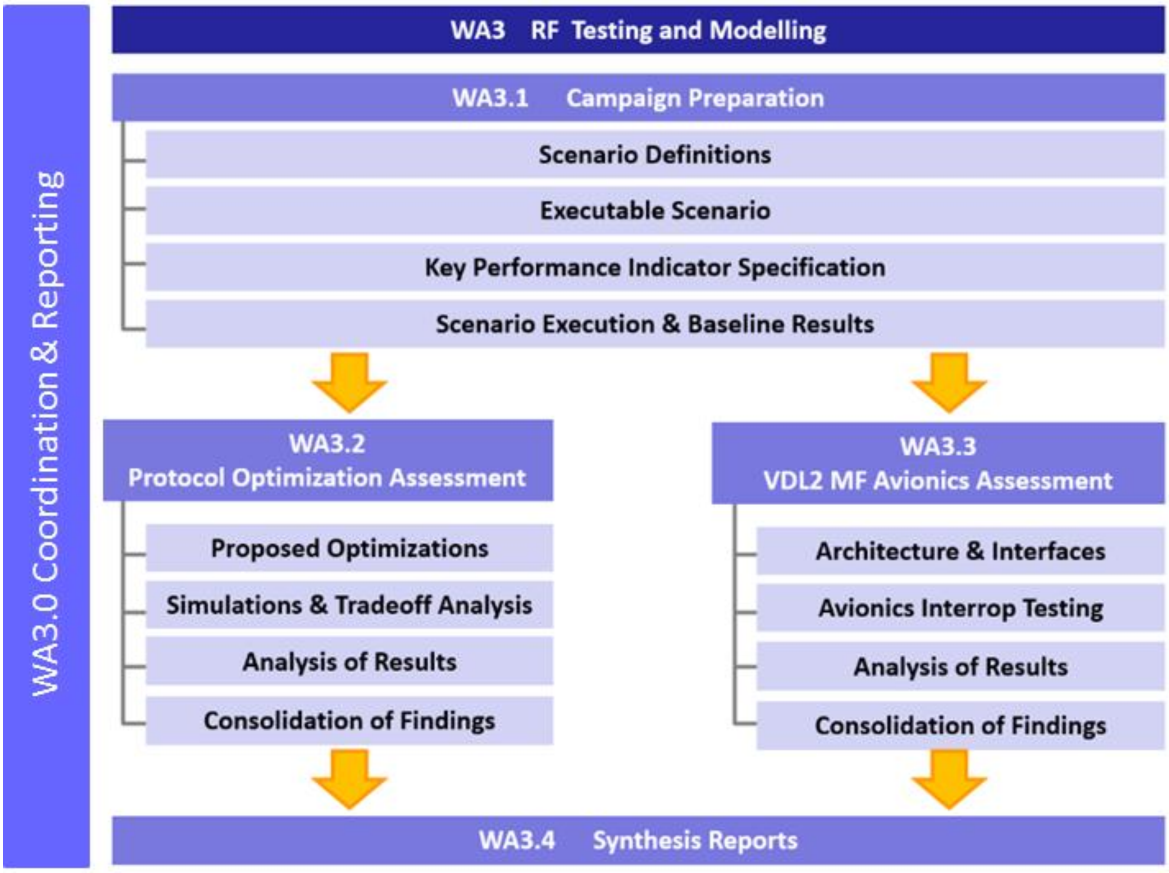


Figure 12 WA3 work breakdown structure (from D10)

3.3.1 Key Performance Indicators

A set of Key Performance Indicators (KPIs) has been defined in ELSA for the measurement and analysis of ATN/VDL2 performance (D10, Appendix B). The scope of each KPI is defined as:

- Global: KPI is computed on a global scope, taking into account all exchanged VDL2 frames including the erroneous ones.
- Per VGS: KPI is computed for each VGS. As the European network includes many ground stations, typical airports (i.e. most loaded) are selected for deep analysis.

- System Under Test (SUT): KPI is computed taking into account traffic seen by the SUT. SUT refers to the avionics that is being tested during Interoperability Tests (WA3.3) or a virtual one selected inside the WA3.1 simulations.

Table 4 KPIs defined for and used by ELSA.

KPI ID	KPI Name	Definition	Global	Per VGS	SUT
KPI_PHY_01	Channel Occupancy	Channel Occupancy is the frames sizes[4] averaged by period (excluding physical overhead such as CRC, training sequence, Reed Solomon…).		X	X
KPI_PHY_02	Channel Occupancy: ATN vs. AOA	Channel Occupancy grouped by payload traffic type (AOA or ATN payload).	X	X	X
KPI_PHY_03	Channel Utilisation (CU)	Channel Utilisation is computed and reported by the VDL2 receiver every second by sampling the channel to determine occupancy every 1 second.		X	X
KPI_PHY_04	CSMA delay	The CSMA delay is the time elapsed between the queuing of a VDL2 message and the transmit time over the RF channel. Results are displayed as a distribution of CSMA values per VGS. The CSMA delay can also be computed for the SUT if the VDR logs (with "MAC delay" logs activated) are provided. In this case, the format of these logs shall be documented and presented before the interoperability tests.		X	(X)
KPI_PHY_05	Channel load/Channel Utilisation/Number of aircraft	This statistic presents 2 views: . channel load compare to the number of visible A/C . channel utilisation compare to the number of visible A/C Channel load is the number of bytes exchanged over the channel.	X	X	
KPI_AVLC_01	Number of simultaneously connected aircraft	Number of simultaneously connected aircraft per VGS. All VDL2-visible aircraft are accounted for, irrespective of their status (airborne or ground-based).	X	X	

[4] Frame size = AVLC frame length in bits

KPI_AVLC_02	PDU occurrences per AVLC type	Number of AVLC frames grouped by type (RR, XID, INFO, SREJ, DM, DISC, FRMR, UA) and different XID are also included (GSIF, LE, HO, GRAIHO, GIHO, LCR)	X	X	X
KPI_AVLC_03	PDU Lengths per AVLC type	Size of AVLC frames grouped by type (RR, XID, INFO, SREJ, DM, and DISC) and XID type (GSIF, LE, HO, GRAIHO, GIHO, and LCR)	X	X	X
KPI_AVLC_04	Total PDU count and load per AVLC INFO Payload type	AVLC traffic frames and load (number of bytes) depending on INFO type: INFO AOA or INFO ATN.	X	X	X
KPI_AVLC_05	Frame size distribution for AOA and for ATN	AOA and ATN frame size distribution.	X	X	X
KPI_AVLC_06	AVLC retransmissions	Number of retransmissions required for each transmission request to succeed (i.e. to be acknowledged by destination, aircraft or ground station). In this statistic, only INFO frames are taken into account. Maximum number of retransmissions is set to 5 by default (up to 6 transmissions in total) and may be modified up to 15 (up to 16 transmissions in total).	X	X	X
KPI_AVLC_07	AVLC round-trip delay	Time required by the system (i.e. aircraft and VGS) to acknowledge receipt of a transmission (uplinks and downlinks). This time is measured between an initial INFO frame (first transmission) and its latest acknowledgment (when retransmissions are observed).	X	X	X
KPI_AVLC_08	VDL2 Link lifetime	Mean duration of a Data Link Entity (DLE): time between acceptance (i.e. LE_RSP or HO_RSP) and next reconnection attempt (HO_CMD or LE_CMD).	X	X	X
KPI_AVLC_09	VDL2 Link establishment mean time	Time between HO/LE command from aircraft and response from VGS.	X	X	X
KPI_AVLC_10	Number of Handovers (HO)	Total number of Handover (HO) frames (command vs. response).	X		X
KPI_AVLC_11	Number of Link Establishments (LE)	Total number of Link Establishment (LE) frames (command vs. response).	X		X

KPI_AVLC_12	Number of DISC	Total number of DISC frames (downlink vs. uplink). Long term view, available in EUROCONTROL MOON tool.	X		X
KPI_AVLC_13	Number of Disconnected Mode (DM)	Total number of DM frames (downlink vs. uplink). Long term view, available in EUROCONTROL MOON tool.	X		X
KPI_AVLC_14	Number of AVLC frames over time	Total number of AVLC frames (downlink vs. uplink and total).	X	X	X
KPI_AVLC_15	Ground N2 distribution	Total number of N2 events for AVLC INFO frames (uplink).	X	X	
KPI_AOA_01	AOA latency	Delay between ACARS over AVLC message and its technical acknowledgement. Results are displayed as a distribution of AOA latency values.	X	X	X
KPI_X25_01	PDU occurrences per X.25 type	Number of X25 PDU grouped by type: CALL REQUEST, CALL ACCEPTED, CLEAR REQUEST, CLEAR CONFIRM, DATA, DIAGNOSTIC, REJECT, RESET-CONFIRM, RESET-REQUEST, RECEIVE READY (RR)	X		X
KPI_X25_02	X25 Clear Request	Total number of Clear Request for the considered days. This statistic is calculated by Hour, but zoom in at the minute/second time units will be considered when required. The KPI will be available for uplink and downlink frames.	X	X	
KPI_IDRP_01	PDU occurrences per IDRP type	Number of IDRP PDUs observed by type: OPEN BISPDU, UPDATE BISPDU, ERROR BISPDU, KEEPALIVE BISPDU, CEASE BISPDU	X		X
KPI_ATN_01	X.25 vs. IDRP	Calculate the part of IDRP traffic over X.25 layer (PDU size in bytes is taken into account).	X		X
KPI_TP4_01	PDU occurrences per TP4 type	Number of TP4 PDUs observed by types.	X		X
KPI_CPDLC_01	Number of CPDLC PDUs	Number of CPDLC PDUs observed (all types of PDUs considered), separately for downlinks and uplinks.	X		X
KPI_CPDLC_02	Size of CPDLC PDUs	CPDLC PDU size distribution.	X		X
KPI_CPDLC_03	Ratio of Provider Abort (PA)	Number of CPDLC sessions leading to a "Provider Abort" situation vs. number of	X		X

		CPDLC sessions that were opened.		
KPI_CPDLC_04	CPDLC round-trip delay	Technical Round-Trip Delays (TRTD) of CPDLC transactions. Time measured between a CPDLC Message (e.g. a Clearance, or a Pilot response) and the associated Logical Acknowledgement (also known as «LACK»).	X	X
KPI_CPDLC_05	Number of CPDLC long delays	Identify and count cases of delayed downlinks and delayed uplinks (for more than 40 seconds).	X	X

4 Findings

The following collection of essential ELSA results and findings, which takes into consideration outcomes from previous work as identified in the literature review, is structured around EASA Actions (see Section 2). Every Subsection also presents the essential activities which provided the findings, and the conclusions. ELSA recommendations are presented afterwards, in Section 6.

4.1 EASA Action 1 – Location of VGSs

4.1.1 EASA Action 1 – Recall of the EASA wording

"The overall locations of VHF ground stations (VGSs) should be designed according to the intended service coverage (airport surface, TMA, en--route). This would mean selecting the appropriate frequencies and adjusting the emitting power of the VGSs according to the required service coverage. This analysis should be performed by taking into account the current AOC and ATN data traffic on one hand and the variations of aircraft traffic flows on the other hand.

Simulations should be performed for the distribution of all VGSs and their associated properties (emitting power, frequencies, etc) for all the services which are to be provided. The model should also take into account the constraints related to the current VGS deployment and the impact on the existing infrastructure.

The next step would consist in deploying a subset of VGS and/or modifying some existing VGS according to the plan. Aircraft flying in the related area should be instrumented so as to confirm the measured radio frequency (RF) interference level with the assumptions in the related technical standards. Both the validation results (successful and unsuccessful) as well as the limitations of the deployment should be documented for subsequent decisions for a larger scale deployment."

4.1.2 EASA Action 1 – Activities performed by ELSA

The ELSA activities and analysis have been based on:

- investigation on the current VGS distribution,
- identification of the most suitable technical solution for the deployment of MF VDL2 infrastructures, in order to ensure the intended service coverage (airport surface, TMA, en-route),
- field analysis based on data collected from operational flights, using initial operational MF deployed systems and MF experimental systems (deployed according to ELSA framework) which have been performed to examine all the technical aspects that could be addressed in the current framework.

To investigate the efficiency of the current VGS distribution and the distribution that should be chosen in combination with a multi-frequency VDL2 system, the ELSA team has:

- analysed data taken from ground logs [6]
- investigated VGS placement considerations [7]

The distribution of VGSs can be linked not only with handovers, but also with the efficiency of the RF channel utilisation. How the VGS distribution should be chosen for multi-frequency deployment is also dependent on the decision whether to use common or reserved alternate frequencies, and on the RF network architecture and technical management model. To accommodate different traffic levels, a scalable approach is needed.

To identify the most suitable technical solution for the deployment of MF VDL2 infrastructures capable of ensuring the intended service coverage (airport surface, TMA, en-route), two approaches have been taken into account:

- Multi-layer RF networks based approach
- Pseudo-cellular architecture approach

The “pseudo-cellular architecture” model for RF network was not considered a possible approach in the current framework of scarcity of VDL2 channels.

Finally, a field analysis based on data collected from operational flights, has been performed to examine all the technical aspects that could be addressed in the current framework. This has been performed using initial operational MF deployed systems and MF experimental systems (deployed according to ELSA framework)

Therefore, the ELSA activities were aligned with anticipated EASA Action 1.

4.1.3 EASA Action 1 – Findings

Ground infrastructure: The overall locations of VGSs should be designed according to the intended service coverage.

For the implementation of the MF VDL2 RF network, two approaches have been taken into account:

- Multi-layer RF networks based approach
- Pseudo-cellular architecture approach

The WA2 study included the VGS deployment analysis (current and long term) and the following conclusions have been reported:

- Special attention will be needed to ensure the CSC coverage over each VDL2 served areas, for both network management and for recovering/emergency functions. This means thatwherever an alternate VDL2 frequency is deployed, CSC coverage for the same area must also be provided.
- ENR and CSC radios shall be operated with the same emitting power, required for the en-route coverage. This is necessary to guarantee CSC coverage among all the VGS operational area.
- VGS implementing only the CSC shall be used only in sufficiently light traffic areas and where the CSC coverage does not overlap with the CSC of an area with high traffic requirements.
- The VGS Multi-Frequency deployment strategy for the long term has been drawn allocating the alternate VDL2 channels for specific functions (TRM or ENR coverage), starting from the current deployment and passing through the short and medium terms.

NOTE: The scenarios identified are representative of the possible strategies of the CSPs. These indicate some guidelines in order to deploy the VDL2 RF Networks, but the actual implementation of those networks is dependent on a number of variables (technical and otherwise). These shall be taken into account in the design phase.

4.1.3.1 SQP Values and GS Coverage Analysis

The Signal Quality Parameter (SQP) is normalised between a scale of 0 and 15 and used to classify the received signal strength. An SQP value between 0 to 3 is considered poor, 4 to 12 is adequate, and 13 to 15 is excellent. The avionics determines the SQP value from the received signal strength (i.e. in dBm) which is mapped to an SQP value according to predefined scales[5]. On the airborne side, the SQP values notified by the avionic VDR are used to determine the need for a handover. During the first batch of data collection and analysis, a possible inconsistency in the SQP values seen from the aircraft was identified. This was dependent on the distance from the aircraft to the VGS. This specific point highlighted that depending on the

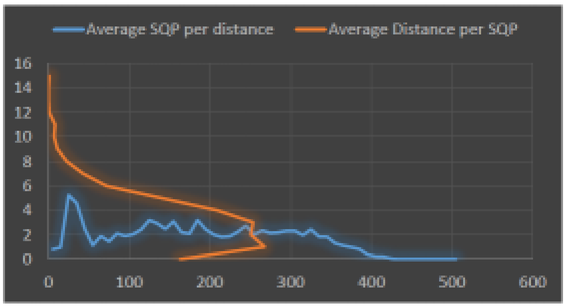
[5] Different scale definitions exist in the different applicable standards: e.g. ESTI standard for ground radios and ARINC 631 or ED 92A for aircraft VDR,

VGS, the SQP seen from the aircraft side was not homogeneous, e.g., dependent on the specific coverage of the site.

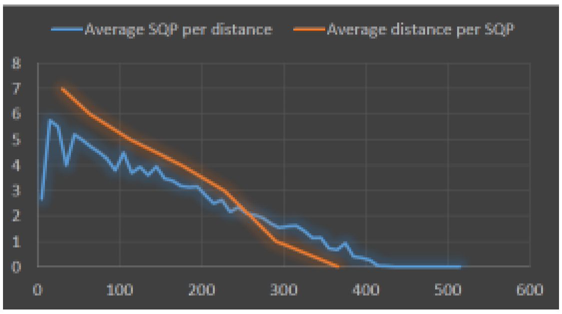
Based on this fact, all data from EZY collected during batch 2 have been integrated to trace SQP over distance curves for some airports (based on ARINC stations only). The data presented is the CMU view and is therefore a filter of the VDR, and also the data collected are based on events (HO and LE).

It is to be noted that graphs are impacted by aircraft paths around the airports therefore the sampling is not completely homogeneous. Also, airports with significant traffic have been chosen and values are based on the means for distance and SQP, therefore extreme behaviours are hidden.

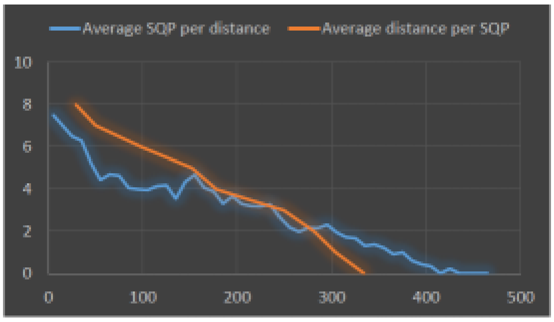
Finally, the number of values per point is not visible on such graphs: the probability of reception associated to each SQP is missing. One example: you only need one value at 400km to state that this is working but the reality may be that the aircraft has captured 1 message over 50 or 1 over 1000.



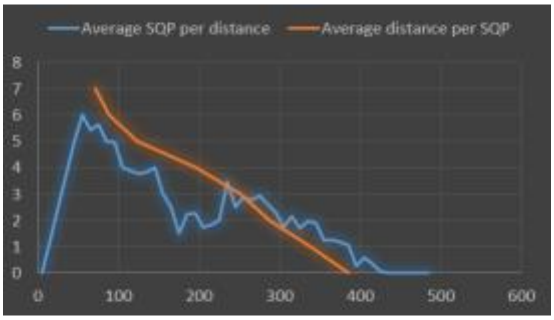
London



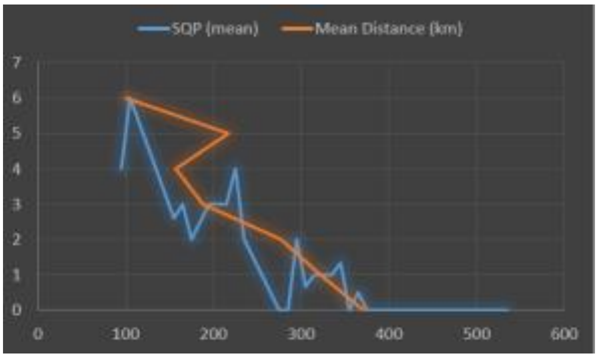
Paris CDG



Frankfurt



Toulouse



Hamburg

Figure 13 SQP over distance for selected airports, from flight recordings (from D08)

Those graphs are showing that no station is seen the same way from the same type of aircraft. All stations can be seen from a distance comprised between 350 and 400 km. The shape of the curves is also variable between the stations that have been analysed.

Therefore, the exact coverage associated to each VGS needs to be taken into account in the station management deployment. This is identified, in D08, as Finding #16.

In addition to this operational finding based on flight logs, a deep dive analysis of CSPs ground logs were also performed (D10, Section 4.5) in order to provide clarification on the current operational network coverage and the main outcomes were as follows:

- Over Europe, the average downlink transmission error ratio is above 5%.
- From an RF point of view, considering the VDL2 sensitivity at -98 dBm, a coverage with high probability (near 100%) of reception could be reached at a distance around 100 NM=185 km. On the other hand at 125 NM=230 km the coverage probability is only 92%.
    - E.g. from an RF point of view, considering Orly VGS as an example: the probability of message loss is around 10% at 250km.
    - E.g. with Toulouse VGS as an example: between 150 and 220km, the failure probability is a very high ~15%.
    - Note that a probability of 10% implies that a HO procedure (HO request/HO response), without any collision, has 19% chance of retransmission.

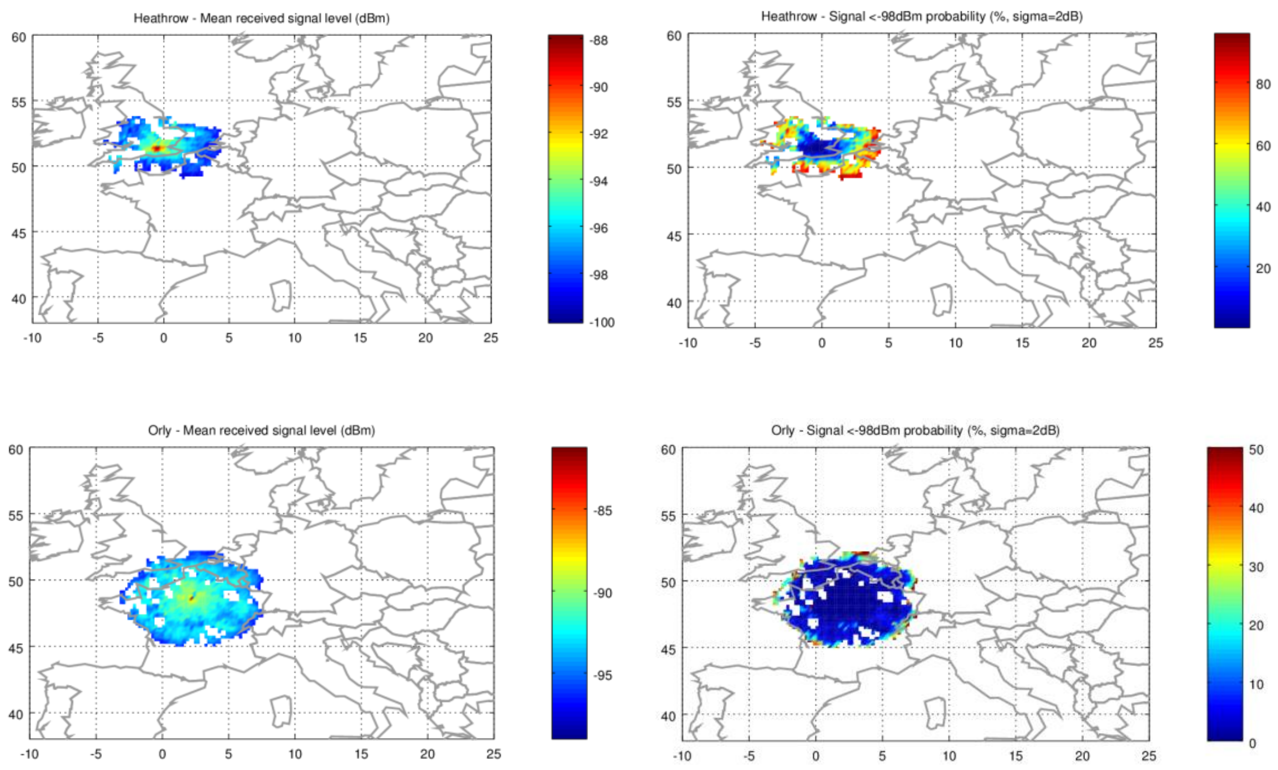


Figure 14 VGS downlink signal level and error probability (ARINC)

- The RF analysis has shown that, some areas have a substantial probability of transmission failure (8% to 15% in the centre of France, 20% in the east of France). This probability represents only the failure probability, due to signal level. It does NOT reflect the message loss due to collision and high CU. This probability is also estimated from the ground radio point of view and it depends on the radio performance.

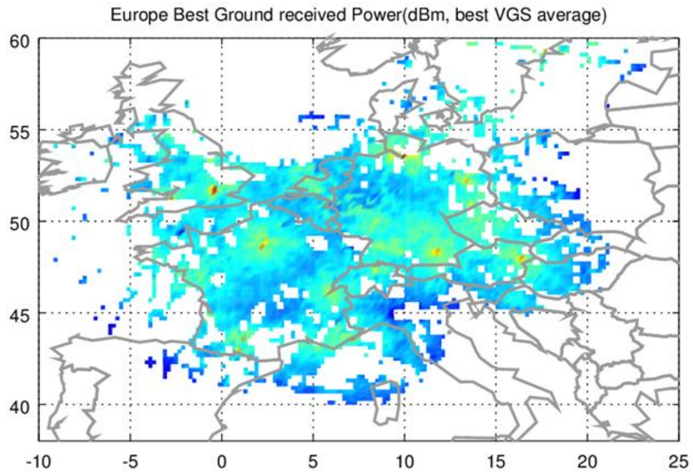


Figure 15 Europe downlink signal level (ARINC); Blue SQP 0, Red SQP 15

- The VDL2 datalink layer analysis, based on the number of retransmissions, showed that the retransmission probability is significant over Europe (~50-60%) and could reach up to ~75% above the Channel.

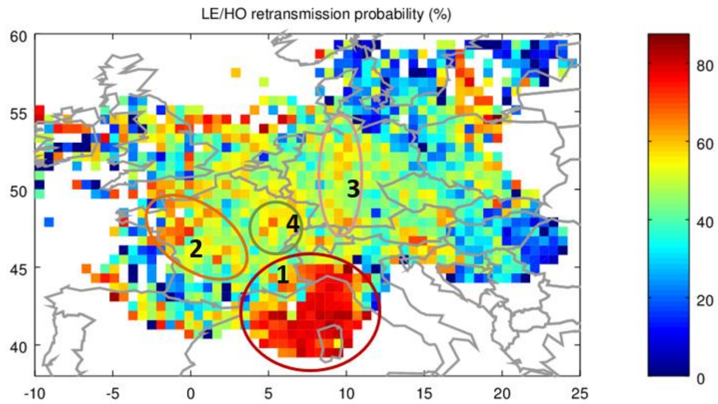


Figure 16 SITA estimated HO failure probability (18 Dec. 2015)

These findings confirm that the theoretical coverage/published coverage do not match the real coverage, and that the VGS and radio channel deployments needed to support CPDLC/ATN performance requirements are not complete:

- Additional CSP VGS and radio channel deployments are needed to improve performance.
- VGS deployment decisions in regions with lower signal strength are always a trade-off between increasing the signal strength and increasing the number of hidden terminal transmissions. Lower signal strength may result in more retransmissions but more hidden terminal transmissions will also result in more retransmissions. The decision to add the additional expense of another VGS must be justified by the potential performance improvement. The analysis required to make this decision takes time and should only be done on a mature network.

4.1.3.2 MF Deployment Strategy

ELSA activities focused on VGS deployment can be condensed in three main steps:

- diagnosis of the existing infrastructures, identifying the high-level requirements and assessing the technical features of the architectures;
- analysis of the data acquired;
- design and development of the proposed technical solutions.

The following main findings were identified:

- Special attention should be applied to ensure CSC coverage over each VDL2 Service area, for network management and for recovering/emergency functions. This means that wherever an alternate VDL2 frequency will be deployed, CSC coverage, at least for the same area, must also be provided.

The picture below shows the different layers of coverage that are to be achieved with the VGS network.

A first layer for en-route service coverage should be deployed over all the EU airspace using an alternate channel only used for aircraft flying in ENR. The number and the position of the VGSs used should be the results of a dedicated VHF radio propagation study, taking also into account the coverage redundancy requirements. A second layer for an alternate en-route service coverage, using a different ENR channel, should be deployed over the central Europe in order to provide the additional resources needed for the high traffic areas.

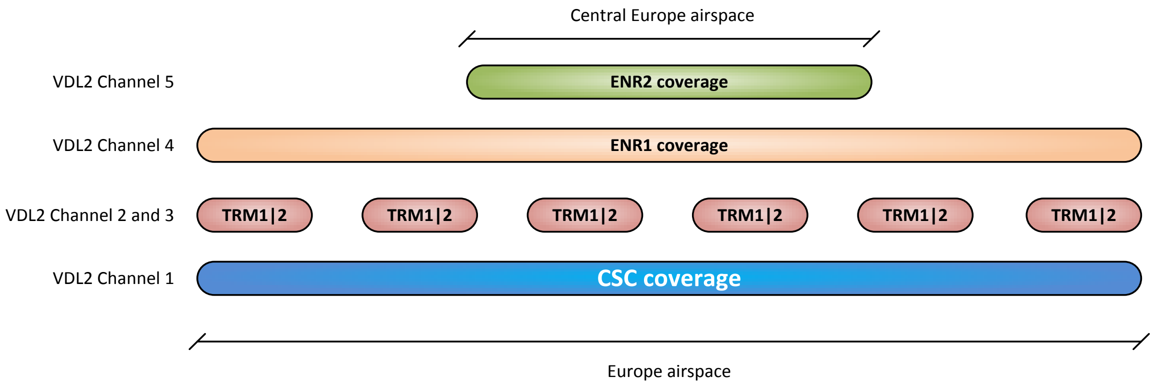


Figure 17 Long term solution VDL coverage layers (from D09)

The MF coverage deployment result (long term) of the study is reported in the following picture.

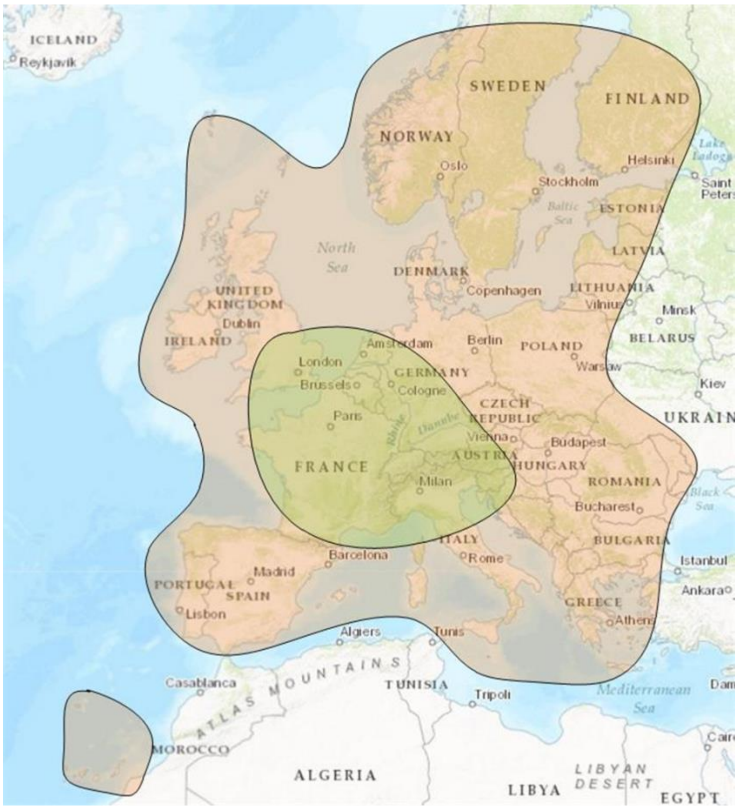


Figure 18 Long term solution ENR1 + ENR2 layers coverage (from D09)

- The VGS Multi-Frequency deployment strategy for the long term has been drawn by allocating the alternate VDL2 channels for specific functions (APT or ENR coverage), starting from the current deployment and passing through the short and medium terms.

  NOTE: The scenarios developed in D09 are representative of the possible strategies of the CSPs. They indicate some guidelines in order to deploy the VDL2 RF Networks, but, the actual implementation of those networks is correlated to a great number of variables (technical and not) that, as is normal practice, shall be taken into account in the design phase.

- ENR and CSC radios shall be operated with the same emitting power, required for the en-route coverage. This is necessary to guarantee CSC coverage among all the VGS operational area.

- VGS implementing only the CSC shall be used only in very light traffic areas and where the CSC coverage do not overlap with the CSC of an area with high traffic requirements

For further details, see Annex G .

CSP interoperability and coordination:

- In general, aircraft shall be moved off of the CSC to alternate VDL frequencies whenever possible. In Service areas with low traffic levels, the CSC may be the only VDL channel needed. The interoperability scenarios between different VDL2 RF networks have been studied for CSP boundary operations indicating the mechanism to manage the frequency changes (see D09 Chapter 4.1.6).

CSPs should have a more formal technical forum to coordinate VDL topics, including: performance on frequencies in use, current RF loading and trends, RF interference issues, RF load threshold triggers, CSC operations and RF deployment plans.

Initial implementation and flight trials:

In summary the data analysis within the trials has confirmed some important points:

- Aircraft can be moved on alternate VDL frequencies using FSL or Autotune effectively, so there is no technical assessment to make on the preference to use Autotune or FSL since they both work successfully (but for some avionics behaviour to be further investigated, as stated also in WA3).

- AVLC performance is very good on alternate VDL frequencies, as expected.

- The analysis of data collected by ARINC, SITA and Skyguide, related to operational flights, confirmed the performance improvements with the addition of VDL2 alternate channels. The CSC, currently almost congested in high traffic areas, has been partially unloaded. In order to use the CSC correctly (serving as the primary contact, management and recovery channel for the network, as stated by ICAO), the process of deploying new MF compatible avionics shall still go on. In fact, using only one APT frequency, there are still many aircraft on the ground with older avionics which remain on the CSC, along with all en-route aircraft.

- ENAV/LEONARDO experimental systems were implemented and operated in Fiumicino airport, effectively managing the transition of operational aircraft among three VDL frequencies (CSC + two alternate frequencies).

  Analysis of data collected from operational flights has confirmed performance improvements with the addition of alternate VDL2 channels.

The results provided by this activity demonstrate the benefits and the feasibility of a VDL-Multi Frequency implementation. See D09 Chapter 4.2 for further information.

4.1.3.3 Simulation of VGS Multi-Frequency Deployment Scenarios

ELSA simulations evaluated four MF scenarios for a 2025 timeframe without any additional optimisation included, see D10 [8], Section 3 for details. Of these, the first three are relevant for the trade-off considerations for network architecture details, and one is covering a pseudo-cellular frequency deployment pattern. The following refers to the VDL2 MF network models described in Section 4.5.3.1 and summarised in the table below:

Table 5 Network models for transition roadmap (from D09)

MODEL	VDL RF operating Networks	VDL RF Frequency Use	GSIF on each Frequency announced by each Network	Existing today	Note
A	MULTIPLE	COMMON	ONE	YES	Current Central EU model
B	MULTIPLE	RESERVED	ONE	NO	**Target Short term evolution for central EU**
C	SINGLE	RESERVED	TWO	YES	Current model deployed in a limited area*
D	SINGLE	RESERVED	TWO	NO	**Target Long term model for EU VDL network evolution**

*Currently deployed by ENAV on Italian airspace.

The difference between Models C and D is that C is currently deployed in a limited area, while D will be deployed in Service areas (see Annex B). A transition process is therefore also needed between C and D. For further information about the models, see Section 4.5.3.1.

Using these models, the simulated MF scenarios can be describes as follows:

MF1: Reserved-single, linked with Model B and C as for the short term – i.e., the scenario based on the currently deployed networks, extended with additional frequencies.

MF2: Common, could be linked to model A for core Europe – a scenario similar to FO4 from the capacity study [10].

MF3: Reserved-dual, incremental frequency usage. Different from the Model D and the target solution – MF3 is a Model D equivalent, with slight modifications: (a) optimised VGS deployment to maximise coverage; (b) incremental MF deployment adjusted to satisfy capacity demand per considered Service areas (the four alternate frequencies of MF3 are allocated for both APT and ENR, while the target solution is foreseeing two APT and two ENR frequencies which would be allocated based on capacity needs). All other items are identical (including the 'two GSIFs capability', i.e. same radios servicing several providers). As such, MF3 provides an upper bound of Model D's expected benefits.

MF4: Reserved-dual like MF3, but with frequency re-use over cell areas.

Same simulation inputs, i.e. flights count, fleet configuration, were used with different ground deployments according to the four identified MF scenarios above. The simulations were performed according to the forecasted European traffic for 2025 horizon, and forecasted equipage and CPDLC usage rates.

Table 6 MF simulated scenarios (from D10 [8])

Scenario name, 2025 horizon	Frequencies count	MF VDL2 Tools	Frequencies assignment	Newly VGS locations	Additional information
MF1 reserved-single	5	Mainly FSL	2 En route, 2 Terminal & CSC	Airports, as today	Radio per frequency per CSP per airport Uplink hidden transmitters issue
MF2 common	4	Mainly FSL	2 En route, 2 Terminal & CSC	Airports, as today	Better with mutualized radios usage Uplink hidden transmitters issue
MF3 reserved-dual, incremental frequency usage	5	GRAIHO, Autotune	4 frequencies equally used & CSC	Hot spot zone	Better with mutualized radios usage Uplink hidden transmitters issue
MF4 reserved-dual, frequency re-use over cell areas	5	GRAIHO, Autotune	4 frequencies equally used & CSC	Hot spot zone with frequencies re-use over cell areas	Better with mutualized radios usage Aircraft tracking required

All simulated deployments made use of 5 frequencies except the MF2 common, which is using 4 frequencies. Each frequency may be used for ENR (en-route) traffic, APT (terminal) traffic, or both:

Table 7 MF deployments, frequency role, 2025 horizon (from D10 [8])

	Frequency role				
	CSC	F2	F3	F4	F5
MF1 Reserved-single	Discovery	ARINC TRM	SITA ENR	ARINC ENR	SITA TRM
MF2 Common	CSC	TRM1	TRM2	ENR	-
MF3 Reserved-dual, incremental frequency usage	Any	Any	Any	Any	Any
MF4 Reserved-dual, frequency re-use over cell areas	TRM	ENR Cell1	ENR Cell2	ENR Cell3	ENR Cell4

Simulations were done to compare 2025 with 2015. From each 2025 scenario the worst channel was taken into account for comparison with 2015 baseline scenario.

A deployment was considered as saturated if at least one of its frequencies is saturated. In order to estimate if a frequency is saturated or not, we calculated the ratio of retransmitted PDU (AVLC INFO). The channel health (calculated based on VDL2 retransmissions and latencies KPIs observed over the channels) was then given with the comparison of this ratio over the ratio or retransmission in the CSC channel in 2015 (reference simulation):

Table 8 MF scenario simulation results – MF4 not presented as it requires further investigations

	Channel Health retransmission: 2025 vs. CSC 2015				
	CSC	F2	F3	F4	F5
MF1 Reserved-single	-73%	-88%	0%	-33%	-84%
MF2 Common	-15%	-90%	-90%	+100%	n/a
MF3 Reserved-dual, incremental frequency usage	-15%	-52%	-8%	-15%	-44%

The following results are expected for 2025 (by considering 2015 to be at the limit of saturation):

MF1, Reserved-single:

SITA ENR frequency **almost saturated** with the given assumption of traffic growth.

As data traffic is distributed according to air/ground status and DSP preference, it is **difficult do discharge** a saturated frequency for this deployment.

Note that RF regulatory authorities typically require proof that a CSP is adequately using all assigned VHF frequencies, before assigning a new frequency.

On the other hand, MF1 relies on the idea that SITA traffic growth on the reserved VDL alternate ENR frequency will exceed the capacity of the channel and there will be no more channels available to support traffic growth. This assumption assumes ARINC was assigned a 2nd alternate frequency and it is not available to handle SITA's traffic growth.

What could likely/also happen is that ARINC could not have enough traffic to justify the assignment of the VDL alternate ENR frequency and the frequency could be assigned to SITA as a 2nd ENR. This case is not taken into account in the MF1 simulation as a possible scenario.

- In 2025, as the traffic is not equally split between the two CSPs (i.e. 60% vs. 40%), one of the en-route frequency is expected to saturate before the other one. Compared to 2015, this en-route frequency will be have the same status as CSC in 2015, before the MF deployment, in terms of channel health (i.e. VDL2 retransmissions and latencies) but the Channel usage (CU) will be ~55% higher than CSC in 2015. Forecasting a good performance of such deployment is not ensured for 2025. This scenario supposes **124** newly added VGSs compared to 2015.

MF2, common:

The single **ENR frequency would not be able** to manage the 2025 traffic.

- In 2025, using 4 frequencies and according to the proposed deployment the en-route frequency F4 will be totally saturated and the channel heath will be much worse than in 2015. This scenario supposes 169 newly added VGSs compared to 2015.

MF3, reserved-dual, incremental frequency usage:

The worst frequency is still acceptable in 2025 (-7.8% of retransmission than on CSC in 2015).

As the traffic is load balanced (using GRAHIO) over available frequencies, additional VGS on F4 or F5 would discharge other frequencies – meaning, an optimised network configuration would show a much better performance margin.

- In 2025, using 5 frequencies deployed incrementally according to airport traffic charge, the channel health will be 8% better than CSC in 2015 giving some float to go beyond 2025. The CU will be comparable to CSC in 2015. This scenario supposes 64 newly added VGSs compared to 2015.

MF4, reserved-dual, frequency re-use over cell areas:

The simulation showed that all frequencies seem far from having degraded performance; however there are significant operational concerns like the transition from on-ground to en-route, as there is only one frequency for CSC and APT. Also, there is a larger gain expected for having scalability from multiple frequencies in one area, instead of having single but non-overlapping frequencies. The operational feasibility also has not been evaluated.

- The scenario requires 5 frequencies to be deployed. The channel health was significantly better compared to 2015, and only 34 additional VGSs compared to 2015 were needed.

The result is showing that it would be beneficial to use different frequencies for neighbouring VGSs serving ENR.

Because all additional frequencies would be used for establishing the ENR frequency pattern, only one frequency is left for APT and CSC. The scenario is not considered to be an option.

4.1.3.4 Pseudo-cellular architecture approach

Another model of network architecture has been taken into consideration in the activities framework. This architecture is based on the so-called “pseudo-cellular architecture” model that does not take into account the inputs considered in the “one/multiple RF networks” approach.

Using this approach, it is possible to evaluate a deployment of a VDL2 network as shown below (Figure 19), where adjacent cells use different frequencies. Each colour represents one of 4 different frequencies.

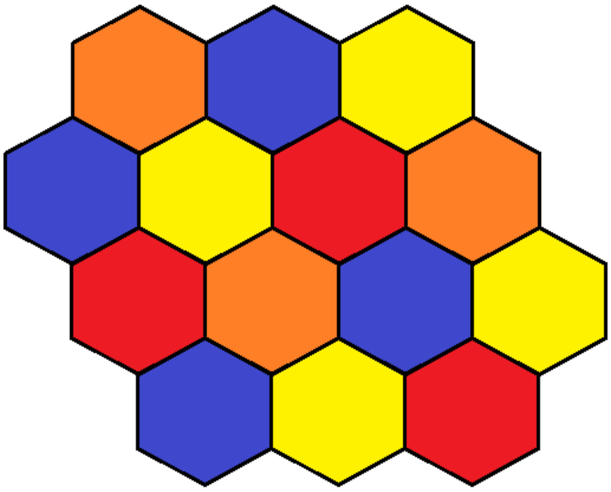


Figure 19 "Cellular architecture" principle (from D09)

As the current situation in terms of:

- ICAO FMG allotment plans (current and draft)
- already deployed RF networks
- existing VDL2 technologies

is not compatible with the "pseudo-cellular architecture" approach, this model has been considered only as an object of studies for the long term solution:

Pros and cons about the possibility to consider the frequency re-use principle in VDL2 environment have been identified, leading to the conclusion that this RF network model cannot be considered a possible approach for a number of reasons, one of them being the scarcity of VDL2 channels in the current framework. Details are contained in D09, Section 4.1.1.

4.1.4 EASA Action 1 – ELSA Conclusions

The various findings on the Distribution of VGSs versus Traffic have shown that:

A. The VGS distribution has a direct impact on the system performance (e.g. HO from avionics, PA localisation).

B. The SQP value covered by the VGS (and seen from the aircraft) is not a sufficient indicator for proper coverage. VGS deployment needs to include parameters such as the probability of success of transmission to determine the exact VGS coverage performance. It has therefore been identified that some regions need additional VGS deployment to ensure a proper probability of transmission success.

In addition to those current operations findings, the proposed MF deployment scenario takes into account specificities such as:

C. A split of frequencies in high traffic areas between ENR and APT frequencies to avoid mixing different traffics.

D. An incremental process of frequency deployment so that the overall capacity matches with the needs from the traffic.

The conclusions related to the overall European VGS coverage could be found also in correlation with Action 5.

4.2 EASA Action 2 - Level of RF interferences for core European area

4.2.1 EASA Action 2 – Recall of the EASA wording

“A representative set of aircraft currently flying in the core European airspace and equipped with avionics having a good record of satisfactory connections should be instrumented so as to analyse the channel occupancy and RF interference level. This data should be compared with the CRO problems’ database and investigations in order to determine if any correlation is evident.”

4.2.2 EASA Action 2 – Activities performed by ELSA

The ELSA activities and analysis have been based on data collected on more than 400 commercial flights performed during both Batch 1 and Batch 2, where more than 7,750 CPDLC messages (both air and ground logs) have been exchanged, representing 700 sessions and 300 hours of duration.

For the first time, ELSA provided an opportunity for all aviation stakeholders to collaborate in analyses, supported by a simulation tool to understand the issue. The revenue flight data collection enabled the identification of the most important issues and facilitated a focus on the main ones. The literature review (including the DLS-CRO’s problems database and investigations) was also a necessary input to the analyses (cf. Chapter 4 of D08).

This data collection has been divided into two batches. The first batch has enabled, associated with the literature review, to accentuate the main VDL2 maturity problems. The second batch enabled a further step from the collection of more data and also permitted a deep-dive on the main topics identified.

Some alternative data collections have been completed by flight tests performed in parallel to the project, including RF recording campaigns.

Most of the flights that have been tracked were equipped with avionics that have proven to have a high level of performance, being part of the “best in class” performance versions.

In addition to the revenue flights data collection, ELSA produced some performance monitoring through the collection of ground logs around the main airports (i.e. AMS, BRU, CDG, FRA, LGW, LHR, ORY, ZRH). The collection of VGS logs has enabled the creation of a very large and comprehensive set of KPIs (including channel loading aspects). The methodology was not to restrict the analysis on the performance (i.e. PA properly followed by EUROCONTROL), but was to isolate some particular behaviours on various sets of KPIs. Once the particular behaviours were isolated, it was easier to identify the possible impact on the performance and the potential associated improvement.

Therefore, the ELSA activities were aligned with anticipated EASA Action 2.

4.2.3 EASA Action 2 – Findings

Results and analysis of the activities performed within ELSA, with a subpart associated to EASA Action 2, are described in Chapter 6 of D08. The goal of this Subsection is to give a summary of those analyses and the associated findings in order to highlight the main aspects that have been identified.

The first set of revenue flight data collection reflected that the source of 75% of the PA encountered during ELSA were due to encountered RF issues. This led the team to specifically deep dive on this item.

Table 9 below indicates the main issues captured with regards to EASA Action 2 and shows where they have been identified across the three different types of analysis.

NB: the same numbering with D08 document has been maintained to keep clarity.

		Literature Review	Batches analysis	Performance monitoring
RF segment issues				
Finding #4	Channel utilisation	x		x
Finding #5	Hidden transmitters	x		
Finding #9	RF channel aspects		x	

Table 9 Review of the ELSA findings associated to EASA Action 2

A deep dive on these critical aspects has been performed during PA analysis and highlighted the following main findings:

- Finding #4.1: Overall saturation of the VDL2 network during peak hours.
- Finding #9.1: Hidden transmitter effect is the main contributor to the RF issues encountered.

4.2.3.1 Overall saturation during peak hours

The maximum channel loading is identified as 38% within the EASA report (and based on a 1998 study named ATN_ED7: COM.ET2.ST15 study phase 1 report).

Ground logs data collected for ELSA has shown that the Channel Utilisation (CU) during peak hours seen by the ground at airport locations such as FRA and CDG was often over 40%. Channel Utilisation (observed at the ground) calculated at peak hour for FRA and CDG shows some peak at 50% (see 1.1.4 of the document attached in D08, Section 14.2.1). Knowing that the CU seen by the airborne is roughly 20% higher, this leads to a minimum 70% during peak time of the peak hours.

4.2.3.2 Analysis of RF Aspects

This Section has been adopted from D08, 7.1.4.

As a mean value at the time of this study, more than one third of the frames uplinked towards an airborne receiver collided and were therefore lost, which lead to additional re-transmissions that increased the CU, and also increased the probability of collision. VDL2 frame collisions can therefore be identified as the main RF issue.

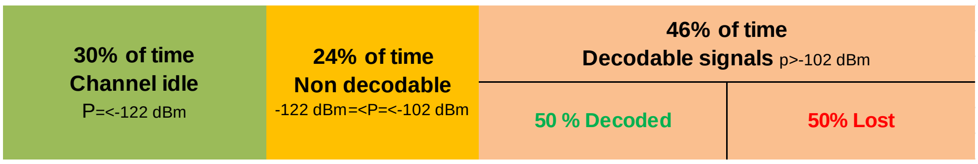


Figure 20 - Typical use of the channel - 1 hour flight – 33% of the decodable frames lost (from D08)

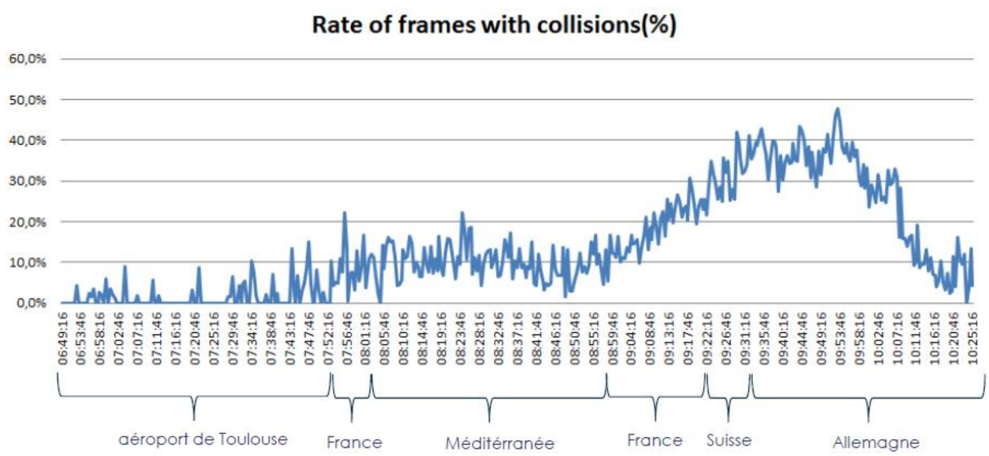


Figure 21 - Example of rate of frames with collisions with frame lost up to 40-45% (from D08)

Moreover, more collisions occurred in a denser VGS network.

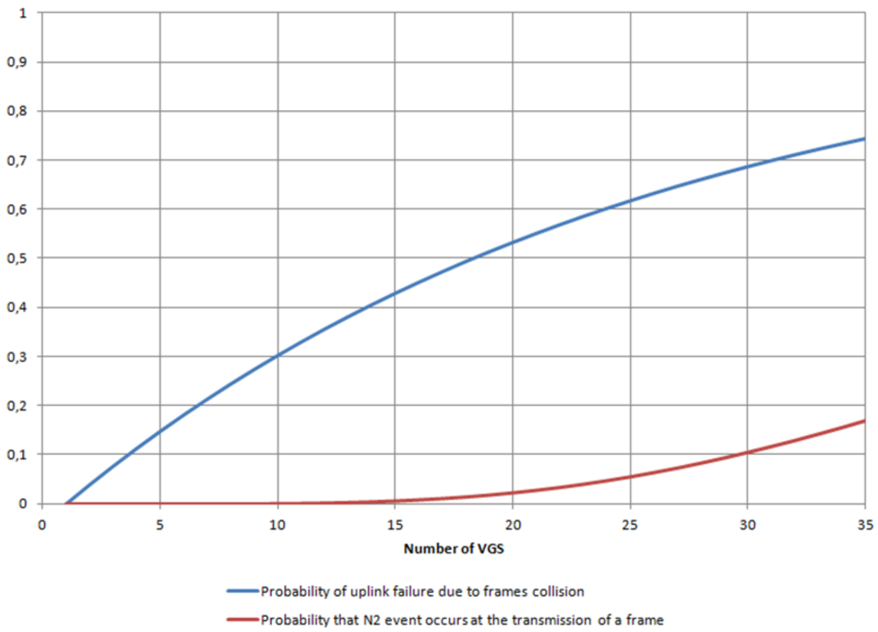


Figure 22 - Probability of uplink failure (collision) & Probability that N2 occurs (transmission of a frame) (from D08)

It is impossible to avoid collisions since they are embedded in the p-CSMA protocol behaviour which is based on sensing the channel. Therefore in essence, a p-CSMA protocol always has hidden transmitters. The goal therefore is to minimise this impact. Since the VDL2 network is supporting “on the ground” and “in the air” communications, it is more appropriate to split those different usage on a frequency basis approach:

- An airborne receiver is seeing all the transmitters from the ground.
- An aircraft on the ground and a VGS only see the surrounding non-hidden transmitters.

By splitting the frequencies on a “per flight phase” basis, it would aid the visibility of VGS per airborne (increasing the capacity of the associated frequency) and it would enable an easing of the frequency on the ground since it wouldn’t be disturbed by the signals coming from the ENR (En-route). Multi-frequency is therefore key.

An additional conclusion on this frame loss rate is that the environment aspect is playing an important role when one frequency is shared.

In a common frequency environment, the VGS deployment from particular CSP should be managed carefully to avoid too many overlapping RF zones (especially true for ENR coverage with respect to multi-frequency deployment design).

As a short term approach, the best way to minimise this type of collision is to have for each CSP (Communication Service Provider) two separated networks in terms of frequency use: one for TRM (Terminal) and one for ENR (En-route). This will also limit the channel load on each frequency.

Moreover, for the “dedicated” ENR network, the associated VGS deployment should be managed carefully to avoid too many overlapping RF zones but also to ensure an appropriate overall coverage (see EASA Action 1).

CCRM has reported that additional interference can occur and that the origin can vary from satellite signals to modulated voice – but those types of interferences represent less than 1% of the transmission time. 1%

may not be that much but during one test flight they have been encountered once (cf. red square on the curve).

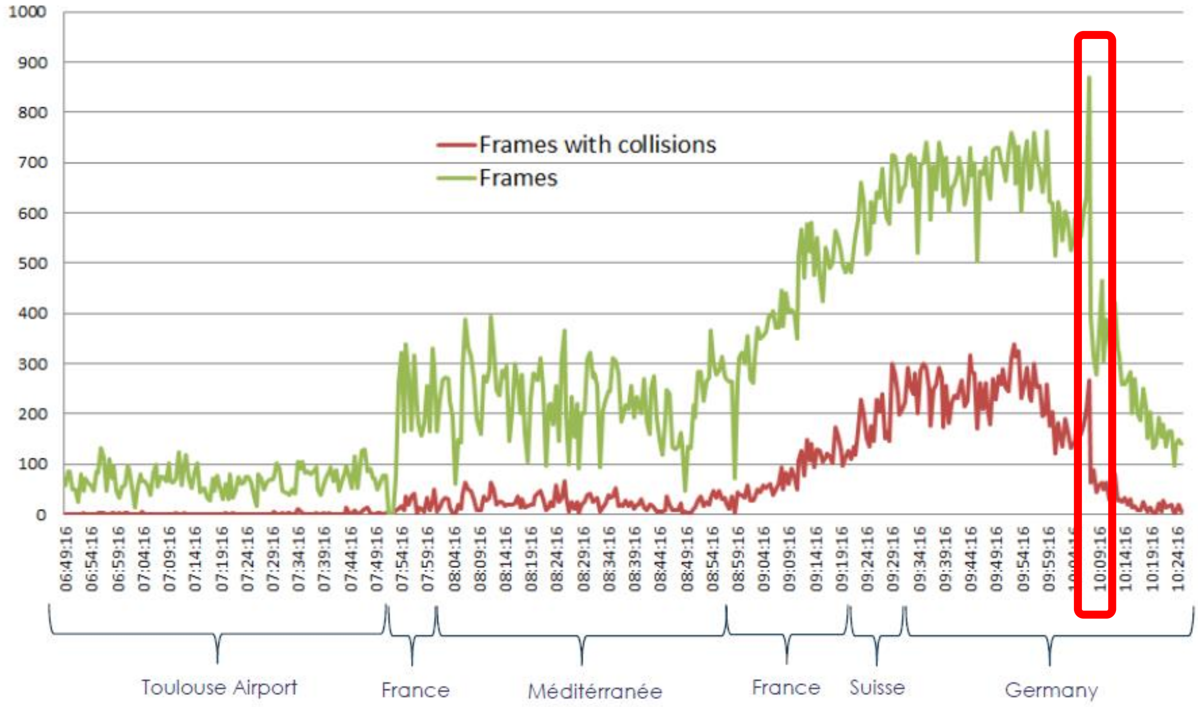


Figure 23 – Example of probable peak due external interference (from D08)

It was considered that it would not be worthwhile spending too much effort and energy on this issue. Although it occurs only 1% of the time, it is nevertheless interesting to highlight it.

4.2.4 EASA Action 2 – ELSA Conclusions

4.2.4.1 Saturation

That the CSC is saturated is known and ELSA confirmed it with performance monitoring measurement. This conclusion of EASA Action 2 is to be associated to the EASA Action 5 ELSA activities and is proving, if needed, that the Multi-Frequency deployment management is also key to provide additional capacity to the network. It is also important to note that gains on the retransmission rate will also improve the capacity usage situation.

Associated ELSA Recommendations are:

- Ground-02: Progressively implement additional VDL2 frequencies in accordance with the traffic level.
- Ground-06: Ensure the availability of a fifth VDL2 frequency (at a minimum).
- Ground-08: Implement the transition roadmap to the MF VDL2 target technical solution.

4.2.4.2 Uncontrolled hidden transmitters effect is a major contributor to the RF issues encountered

ELSA activities showed that the “uncontrolled” hidden transmitters effect is a main contributor on today’s uplink retransmissions rates and therefore on the overall performance of the network. This finding is associated to:

- AOA traffic not being dominant in ENR,
- Balanced traffic between AOA and ATC at VGS level,
- 60% of the traffic coming from the ground with roughly 20% dedicated to exchanges with airborne on ground,

are showing that short-term effort is to be placed on traffic segregation rather than on developing a prioritisation management between ATC and AOC.

Nevertheless the long term view in terms of capacity usage has to be taken into account from today, since if it is anticipated from now on that the AOA traffic can be offloaded gradually, the capacity usage of the TRM will decrease and then the segregation would be reviewed to have frequencies reallocated e.g. to both TRM and ENR.

The ELSA activities have also proven that the RF aspects are key for such a system. Therefore it is mandatory to guarantee proper performance of the RF transmitters and receivers.

Associated ELSA Recommendations:

- Ground-01: Use a dedicated channel for transmissions at the airport level in Service areas with high traffic levels in ENR,
- NetworkOversight-03: Establish a pan-European ATN/VDL2 end-to-end certification function for validating (ground and airborne) sub-systems' radio acceptability,
- Ground-07: Favour alternative communications means for AOC, with a priority to the airport domain.

4.3 EASA Action 3 - Hot Spots and Airborne Algorithms, especially Handover

4.3.1 EASA Action 3 – Recall of the EASA wording

"The current zones in the airspace and times showing the highest AOC/ATN load should be identified. It should be analysed whether the airborne algorithms as defined in the relevant technical standards can suitably cope with the intended use.

There should also be a complementary proposal for a method suited to the European airspace for the ground management of VGS ground-requested air-initiated handovers. Such method should be prototyped and trialled. There should be a comparison of the limitations between the air-initiated and the ground-requested air-initiated VGS handovers."

4.3.2 EASA Action 3 – Activities performed by ELSA

The literature review performed during ELSA confirmed that the avionics Handover (HO) is a key component of the performance issue. In order to properly analyse the link between the HO and the performance, different activities have been conducted based on the following questions:

- How does the HO cope with the situation created by the VGS distribution and the "hot spots"?
  - Answer: based on ground logs, the number of HO per aircraft per area has been plotted on a map, on a per CSP basis.
- Is there also a link between this distribution and the localisation of the PA?
  - Answer: ELSA simulations gave the possibility to match the PA distribution with the same kind of map.
- How do HOs currently impact the channel capacity?
  - Answer: KPI monitoring gave the opportunity to understand the current impact of the HO on 7the channel capacity usage for the ENR.
- How do the "best in class" avionics trigger the HO? Any improvement?
  - Answer: KPI monitoring and operational analysis allowed identifying if the last upgraded algorithms mechanisms have improved the situation.

With those activities, ELSA had been able to identify how the HO mechanism is impacted by the ground system deployment. In addition, ELSA had the capability to differentiate the "best in class" HO behaviour.

ELSA took into account that the current operational management of the handovers is either air-initiated or ground-initiated.

Therefore, the ELSA activities were also partially aligned (on purpose) with the anticipated EASA Action 5. Only the complementary proposal for a method suitable for the European airspace for the ground management of VGS ground-requested air-initiated handovers was not performed since it was out of ELSA scope.

4.3.3 EASA Action 3 – Findings

4.3.3.1 Distribution of Handovers

The following is a summary of D08, Section 7.2.2.3.2.

The goal of this analysis was to assess where HOs are frequent, and how this can possibly be caused by the VGSs' distribution.

Handover statistics have been built based on the HO localisation for avionics provided by ARINC for April 6th and 7th 2015. These also contained relevant information for SITA. The HO position is fetched from the "Aircraft location" fields in the HO/LE requests, when available. The following two maps show the HO count identified on a per aircraft basis. Note that it is likely that some HO data is missing, especially in the SITA network. Some areas can be identified as showing unusually many handovers, in both networks. It is to be noted that the North Sea zones have not been taken into account since there is no coverage over that region.

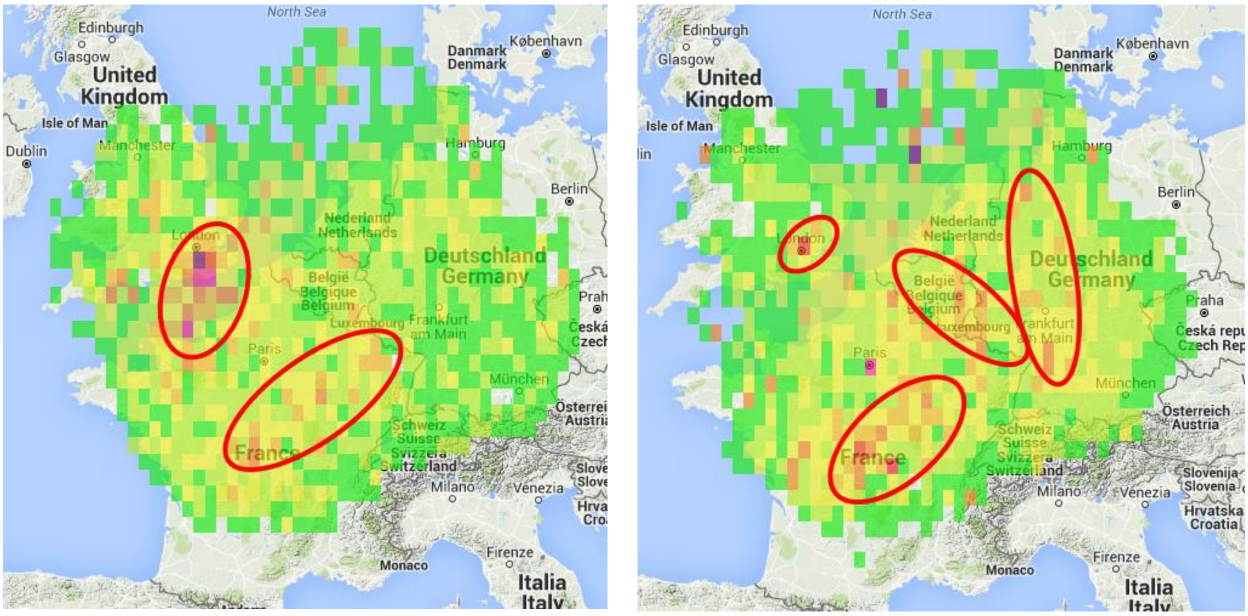


Figure 24 "Unusual" hand-over areas in the two VDL networks (from D08)

In order to reason about these "unusual" hand-over areas the VGS distribution has to be considered as the most likely contributor. Note that, at the time this data was taken, all VDL2 VGS were using the same frequency.

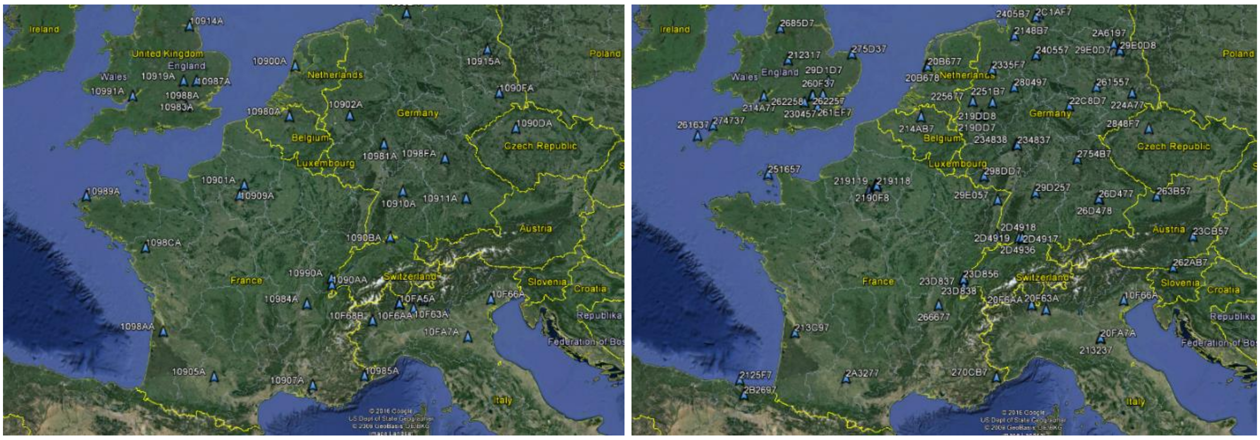


Figure 25 VGS sites (mid-2015) of both networks (from D08)

By comparing Figure 24 and Figure 25, the areas where many HO occur (on a per-aircraft basis) can be linked to areas where there are either many VGSs, or only few of them.

It is important to note that the second frequency deployment in October 2015 has significantly improved the situation. The count of ARINC received HO at each ground station is seen to be almost half that of June.

4.3.3.2 Distribution of PAs

The following is summarizing the activities described in D10, Section 2.6.

The simulations were executed using scenarios built from live data of April 2nd 2015, chosen for being the busiest day of the second quarter. Both ARINC and SITA have provided full VGS logs for that day. 17 Provider Aborts were experienced in European airspace that day.

A detailed analysis of the PA experienced shows that:

- About half of the PAs are related to low coverage areas (Figure 26 left, yellow boxes). The low coverage area was identified by taking a circle of 150 km around each VGS, where signal strength is supposed to be high enough to maintain a good VDL2 link.
- The other half of the PAs are in areas where uplink collisions are high (Figure 26 left, red boxes). In these areas, the density of traffic as well as of VGSs seen in the en-route is high.

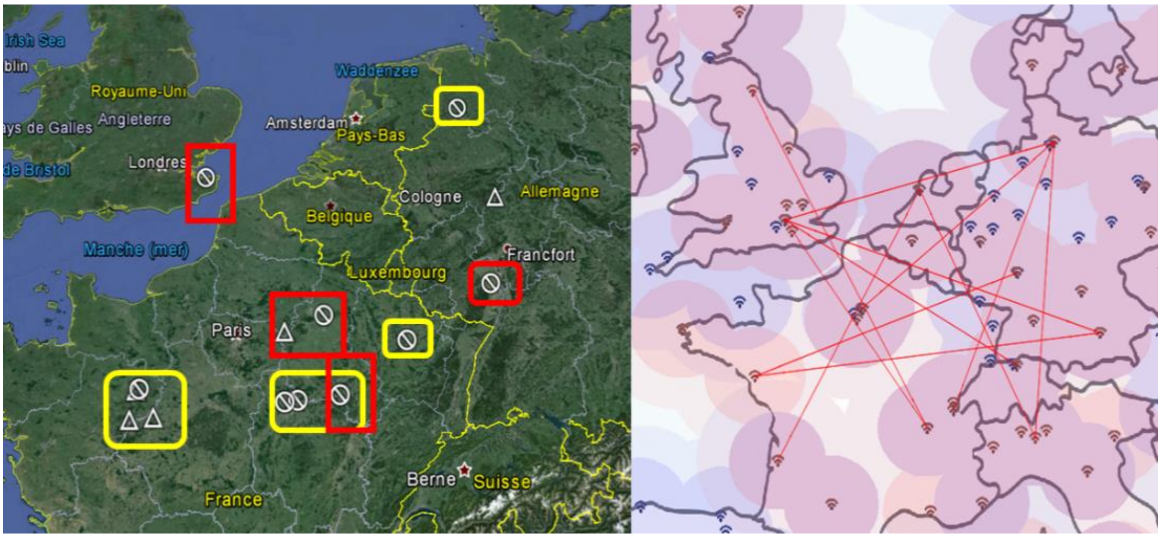


Figure 26 left: PAs (circle), long delays (triangle); right: coverage and routes (from D10)

Due to the low number of samples (PAs) another KPI, long delays, has been used as well to identify problem areas. A detailed analysis was still not possible based on this overview, but areas identified here were relatively close to the areas where unusual numbers of handovers have been seen.

4.3.3.3 HO Contribution to Traffic Volume

Details can be found in D08 Section 7.3.3.2.3.

The traffic data below, in Figure 27, reflects the distribution between AOA/ATN and others with sub-categories which are Downlink from airborne aircraft (DA). Analyses have been performed on May 2015 data. CO, Channel Occupancy, is measured as the sum of the PDU frames' sizes (in bytes).

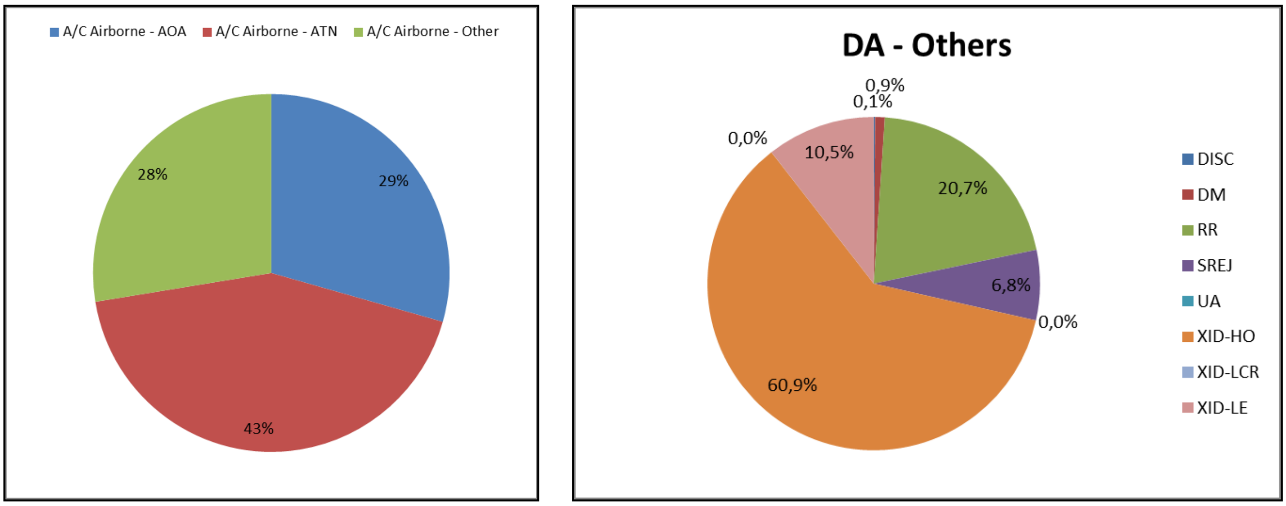


Figure 27 Airborne PDU type distribution (size) (from D08)

It can be seen that around 30% of the airborne traffic is used for managing the VDL2 connection. Of this data, around 60% is coming from the HO management. It means that, at the time of the study, 18% of the ENR traffic was dedicated to the HO management.

Any possible improvement on the number of HO will be beneficial for the Channel Usage in the ENR phase.

This is identified, in D08, as Finding #20.

To complement the results of the channel usage monitoring, it has been decided to deep dive on the difference of statistics on this HO topic between the "best in class" and the "typical" ones. The KPI "Mean timeframe on one VGS" has permitted to demonstrate this improvement. This statistic gives a view on the behaviour of the avionic that used to switch very fast from one VGS to another. The Mean Timeframe on One VGS is the mean time spent by each aircraft on an individual VGS. The smaller this value is, the more HO the aircraft is performing along a flight path.

This specific statistic has been split between the "Best in class" and the "Typical" configurations[6].

[6] Both airborne and landed aircraft have been considered for this analysis. Splitting would have been unfortunately too complex to set-up in the ELSA timeframe. Therefore the "long" connection is probably linked to aircraft on the ground more than to airborne.

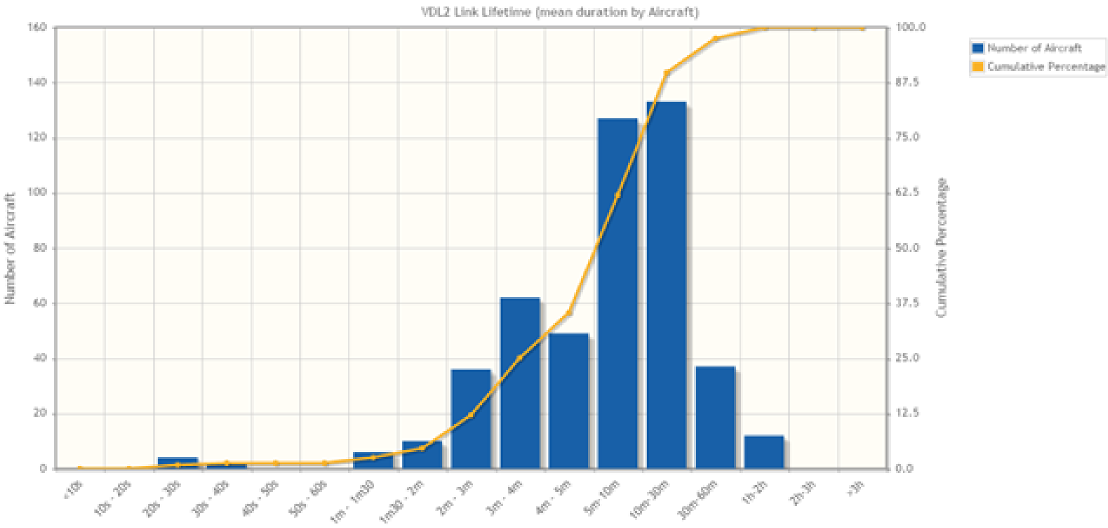


Figure 28 Mean timeframe on one VGS – "Typical" avionics (from D08)

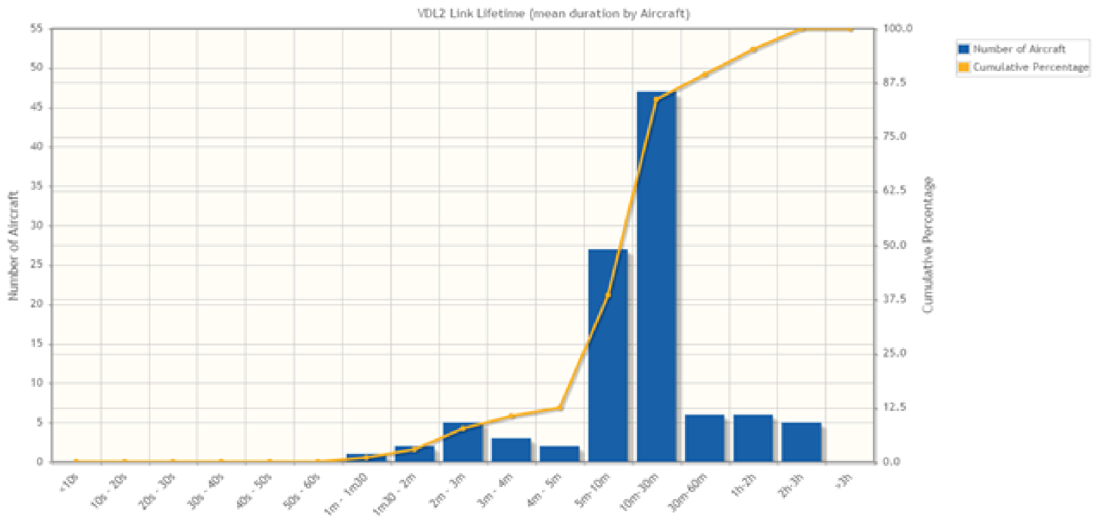


Figure 29 Mean timeframe on one VGS – "Best in class" avionics (from D08)

The second graph is showing that, on average, the "best in class" avionics are less suffering of an "HO storm" where numerous HOs happen in a short duration.

This is identified, in D08, as Finding #6.2.

4.3.3.4 Handoff Avionics Analysis

Avionics suppliers shared the main principles for handover management. A detailed study was conducted by avionics partners in order to analyse the main reasons behind aircraft handovers (cf. D10). In congested areas, or areas where there was a lack of coverage, the number of handovers increased drastically for all avionics configurations with a trigger for HO necessarily not coming from the on-board HO algorithm but mostly from the lack of success of the transmissions. The interoperability tests identified differences between avionics implementations which led to various levels of reliability in maintaining connectivity under such conditions. Therefore, HO algorithms could be enhanced based on guidelines identified in the simulation results, and this topic should be brought to the appropriate standardisation body.

These possible enhancements have to be considered in parallel with a comparison of the limitations between the air-initiated and the ground-requested air-initiated VGS handovers (cf. D09). The main benefit of using

GRAIHO is that the ground VDL multi-frequency processing function can control the loading of individual frequencies with knowledge of the network load across all VDL frequencies. The ground based VDL multi-frequency processing function is the system entity with the best knowledge necessary to implement deterministic RF loading algorithms. This VDL multi-frequency processing function receives data from on-going data-link operations and determines the best frequency/radio for each aircraft. The appropriate ground station sends a GRAIHO message to request that the aircraft does a retune to a new frequency and a handoff to a new radio.

4.3.4 EASA Action 3 - ELSA Conclusions

4.3.4.1 The current single frequency VGS deployment in some European regions leads to ineffective HO avionics behaviour (impacting the overall performance)

ELSA has demonstrated through the HO maps presented early in the document and the fact that 30% of the airborne traffic is focusing on managing the VDL2 connection that the amount of HO managed at the avionics level is dependent not only of the algorithms set-up on-board but also of the environmental aspects, i.e. the VGS distribution. Therefore particular care should be taken on the design of the ENR VGS distribution. The exact VGS coverage as well as SQP and transmission success probability are items that should be taken into account to support the guidelines for network deployment.

Associated ELSA Recommendation:

- Ground-03: Optimise the ENR VGS network coverage.

4.3.4.2 “Best in class” are managing the HO more efficiently

The monitoring of the “best in class” avionics allowed ELSA to prove that those avionics versions have enhanced their HO algorithms. In parallel, ELSA has shown that “typical” avionics are using 18% of the ENR channel capacity only for HO. The upgrade to “best in class” performance avionics will shift usage rates in favour of the useful part of the channel.

Associated ELSA Recommendation:

- Avionics-01: Upgrade of avionics to the “best in class” performance.

4.3.4.3 Need for harmonised HO management

ELSA acknowledged that improvements of the algorithm at the avionics level are still possible. Nevertheless air initiated VGS handover is not the only possible solution that the standards are offering today. ELSA discussions led to the conclusion that a further deep dive is needed on the HO management. Those discussions should be carried out soon for keeping the current momentum where ground and avionics manufacturers need to work closely together. The goal is to answer to the second part of the EASA Action 3 which is “There should also be a complementary proposal for a method suited to the European airspace for the ground management of VGS ground-requested air-initiated handovers. Such method should be prototyped and trialled”.

Associated ELSA Recommendation:

- Standards-02: Include the selected interoperability improvements and clarifications in the relevant standards.

4.4 EASA Action 4 - Concurrent AOC and ATN Traffic Management

4.4.1 EASA Action 4 – Recall of the EASA wording

“Simulations and analyses should be used to determine the maximum channel occupancy when concurrently managing AOC and ATN protocols under the conditions of the intended use. This should be performed with different frame lengths. Other network management techniques compatible with VDL2 could be proposed. Limitation to the frames of AOC traffic, balanced to allow adequate performances of both AOC and ATN data traffic should be also foreseen, and potentially being required in an update of the DLS regulation.”

4.4.2 EASA Action 4 – Activities performed by ELSA

Based on the CSPs’ data collection (logs), various KPIs have been defined to monitor the ratio of traffic including AOC and ATN both on the airport level and during en-route. It is known from 1990’s studies that one channel could be loaded up to 38% before starting facing saturation issue, whatever the traffic is that is loading it. It is therefore very important to understand if the concurrence between AOC and ATN is a specific or a constant issue.

The action taken within ELSA was therefore to deep dive on the traffic split and the real traffic sharing, to focus on the appropriate actions.

Moreover, one of the optimisations that has been deeply analysed was the reduction of the VDL2 frame size (see 5.3 of D10). In 2015, the AOA protocol was the main source of long AVLC frames. The side effect of transmitting long AVLC frames is the channel occupancy induced in case of retransmission, in addition to increasing the probability of uplinks collisions. This is why very long AVLC frames should be avoided mainly when the overall channel occupancy is high.

4.4.3 EASA Action 4 – Findings

4.4.3.1 AOA versus ATN Traffic

Adopted from D08, Section 6.2.2: The KPI enabled to highlight that AOA traffic was at 90% AOC traffic (the remaining 10%were ACARS-based ATC & FIS services like DCL (ED-85) and D-ATIS (ED-89)). The KPI also showed that channel utilisation was overall equally split between AOA traffic and ATN (CPDLC) traffic.

A deep dive investigation has been performed on this KPI since it has been considered interesting to split the type of traffic into 3 categories: AOA, ATN and VDL2 management[7]. The KPI has been analysed at different stages of the exchanges between the aircraft and the ground connection management.

The input data is ground log files and MOON data from major European airports, from one busy day, evaluated during peak hours (see D08, Section 6.2.1).

It was possible to identify the split of the traffic at the transceiver position level. Those transceivers are the airborne aircraft, the aircraft on the ground and the VGS.

[7] The view of the % of the channel utilisation dedicated to the VDL2 connection management was mandatory to identify where the capacity was used.

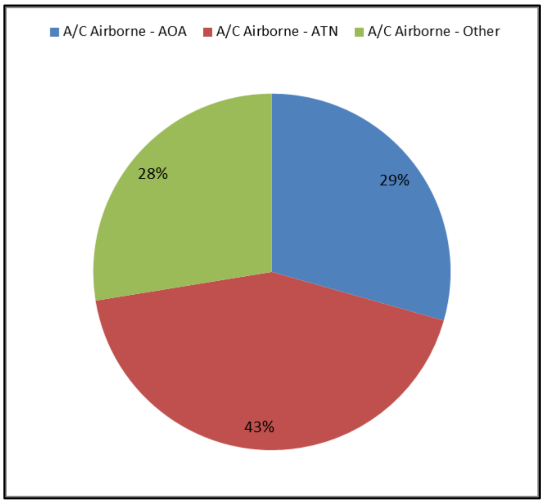


Figure 30 – Downlink Airborne (DA) PDU type distribution (size) (from D08)

Figure 30 shows that the concurrence between AOC and ATC is largely in favour of ATC in the En-Route phase.

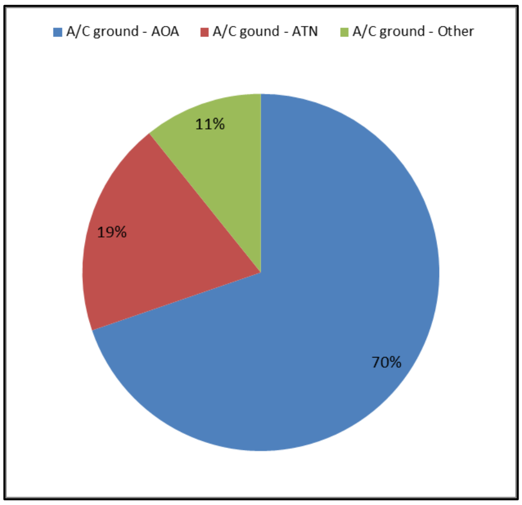


Figure 31 – Downlink Aircraft on the Ground (DG) PDU type distribution (size) (from D08)

Figure 31 shows that 70% of the traffic of the aircraft on ground (effectively 29% of the total) is AOA only.

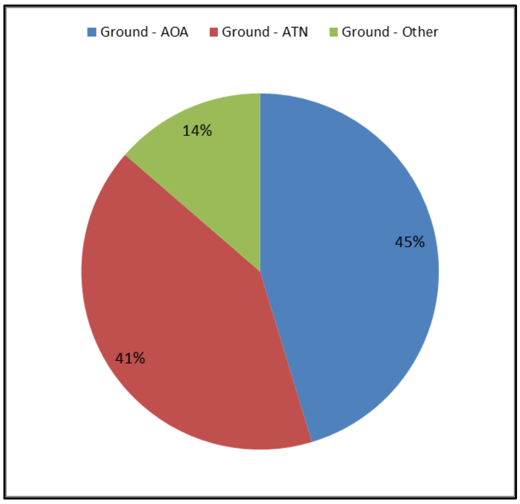


Figure 32 - VGS PDU type distribution (size) (from D08)

Figure 32 shows that the VGS traffic is equally balanced between AOA and ATN in terms of PDU distribution (size). Based on the raw data collected, it was also possible to identify, from the ground stand-point, where the traffic was coming from. This also helped to understand the way the traffic is exchanged.

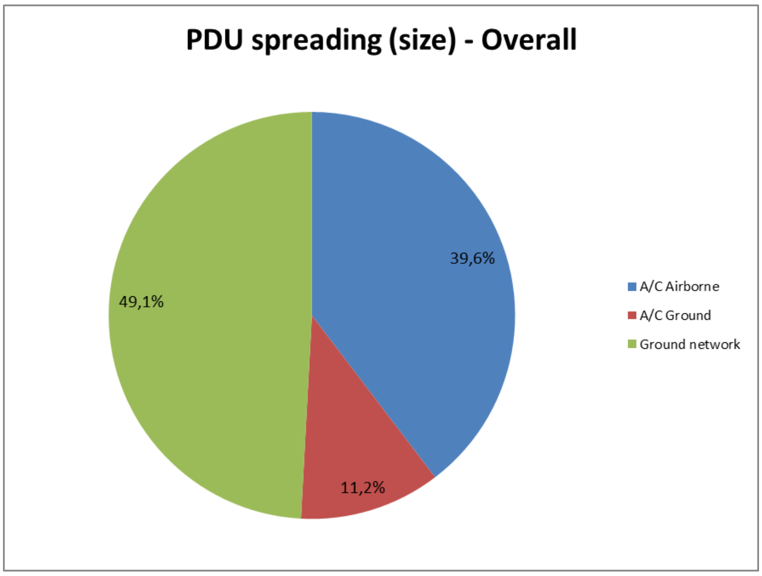


Figure 33 - Overall - PDU type distribution (size) per transceivers type (from D08)

Figure 33 shows that 60% of the traffic (size) is coming from the ground[8]

4.4.3.2 Reduce VDL2 frame size

Very long AVLC frames should be avoided mainly when the overall channel occupancy is high. Consequently, a protocol optimisation has been proposed and studied (cf. 5.3 in D10) in ELSA. This optimisation consisted on reducing the AOA frame size by reducing the AVLC N1[9] parameter to match the average ATN frame size while still allowing an AVLC frame to contain one AOA packet (i.e. one ACARS block). The proposed value for N1 is 251 bytes as this value is sufficient to support the ATN B1 messages as the distribution of the VDL2 frames length conveying ATN payload is as follows:

~30% of the captured VDL2 frames have a length = 48 octets,

~97% of the captured VDL2 frames have a length ≤ 128 octets.

Note that this optimisation is a short term answer (applicable for ATN B1) that has to be reconsidered in the near future with the deployment of the ATN Baseline 2, when long ATN messages are expected to be needed.

4.4.3.3 ATN/AOA prioritisation at ground level

In order to answer the long term horizon, the ATN/AOA prioritizing at ground side has been also studied as another optimisation topic (cf. 5.16 in D10) and assessments have been performed through simulations and analysis. The main outcome is that an aircraft doing ATC communication could be affected by AOC traffic in the vicinity. In other terms, an aircraft doing long AOA messages could negativity impact the performance of the surrounding aircraft, as illustrated in the figure below when no QoS management exists.

[8] The Uplinks from Ground network are sent to aircraft on the ground as well as airborne aircraft.

[9] The parameter N1 defines the maximum number of bits in any VDL2 frame

In order to avoid such situation, basic QoS rules need to be implemented to allow a secure and seamless segregation of the data paths.

For the QoS rules, it is required to segregate data by at least two things: one is by its importance, and the other is by its volume. As a general rule, important data typically is not high volume; it is low volume.

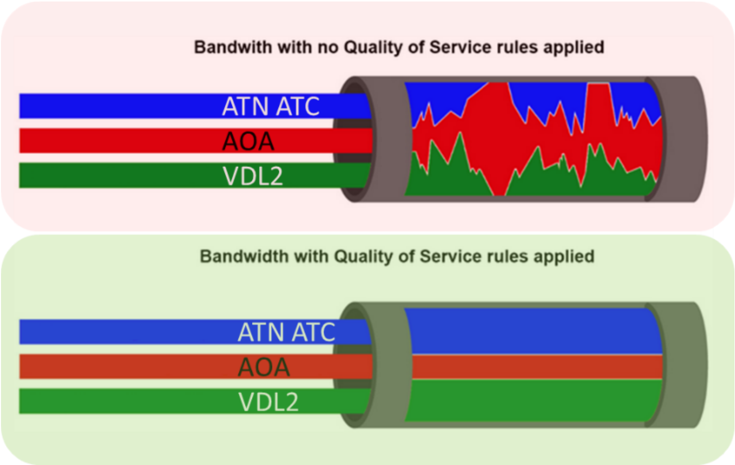


Figure 34 Bandwidth with no QoS applied vs. QoS applied (from D10)

The recommended activities were:

QOS rules definition for ATC & AOC sharing (over the VDL2 channel) have to be clarified and to be followed-up by the standardisation groups.

4.4.4 EASA Action 4 – ELSA Conclusions

The deep dive analysis shows that the sharing of channel usage between AOC and ATC contributes to the overall congestion of the frequency (mostly at the airport level), even though it is not the main contributor to the ATS problem because AOC data traffic does not dominate in ENR.

To mitigate this issue, two short term (matching the current ATN B1 deployment) actions have been identified:

- Split the frequencies on a usage basis, dedicating a frequency to the airport domain;
- Limit the size of AOA message compared to the ATN ones by reducing the AVLC frame size. This consists on updating the ground configuration that notifies aircraft with the allowed maximum AVLC frame size. 251 bytes was proposed.

Also a long term answer has been also studied, which consist on defining QoS rules for ATC & AOC sharing over the VDL2 channel. These topics have to be clarified and followed-up by the standardisation groups. In addition, it is needed to anticipate the move of AOC traffic to alternative communication means, at least at the airport level.

Associated ELSA Recommendation:

- Ground-01: Use a dedicated channel for transmissions at the airport in areas with high traffic levels in en-route.
- Ground-06: Implement ELSA recommended protocol optimisation: limit the AVLC frame size.
- Ground-07: Favour alternative communications means for AOC, with a priority to the airport domain.

4.5 EASA Action 5 – Management of the Air/Ground Communication Service Provision

4.5.1 EASA Action 5 – Recall of the EASA wording

“There should be a technical trade-off analysis of the constraints and benefits arising from a distributed infrastructure (where intermediate providers such as ARINC or SITA provide some services) compared to a fully managed infrastructure (where the ACSP is completely in charge of its network) up to a fully centralised model. The assessment should derive the constraints to be imposed on the distributed constituents and on the governance processes in order to guarantee the expected performance for the network. The evaluation should establish how the control of the infrastructure could be performed in all cases.”

4.5.2 EASA Action 5 – Activities performed by ELSA

The ELSA activities and analysis have been based on:

- investigation of three different models for managing the DLS provision, and
- identification of system architecture both for a single Service area and at European level.

In ELSA three different models for managing the DLS provision have been investigated:

- Service model: a CSP deploys, owns and operates the VHF infrastructure over a given airspace. It provides the air/ground communication service (VDL2 and ATN routing) against a regular fee to the ANSP. The ANSP should contract all CSPs providing a compliant service in the airspace in question, according to the provisions of the Implementing Rule
- Partnership model: an ANSP procures the VHF infrastructure from a CSP, owns and operates it, and provides the air/ground communication service (VDL2 and ATN routing) to aircraft. This communication service is advertised to aircraft as the CSP(s) service. The ANSP provides the AOC service as well on behalf of the CSP(s).
- Development model: an ANSP designs, specifies, develops and deploys the VHF infrastructure (possibly through contracts with industrial partners). The ANSP then owns and operates the delivered systems. The ANSP provides the air/ground communication service (VDL2 and ATN routing) to aircraft on the deployed infrastructure. The ANSP may enter into an agreement with CSP(s) to support the AOC traffic on their behalf, and advertised it to aircraft.

  Considering that most of currently DLS issues are on RF segment of DL system, the ELSA technical effort has been focused to identify the most suitable MF infrastructure at RF level, for both single Service area and at European level (considerations about centralised versus distributed infrastructures have been done),

Therefore, the ELSA activities were aligned with anticipated EASA Action 5.

4.5.3 EASA Action 5 – Findings

It was recognised that the different Ground RF network architectures could be identified using a combination of few characterisation factors:

- **Number of different RF networks** (operated by different providers) in the same Service area.
- **Type of frequency licensing** (or allotment) used for the VDL2 channels.
- **Type of GSIF advertisement** operated on each channels

So, based on conclusions coming out both from the Technical Analysis (D09 § 4.1.1 ÷ § 4.1.7) and from the Field Analysis (D09 § 4.2), the trade-off analysis has been conducted by considering the behaviour of the options with respect to the identified topics, identifying which of them guarantees the best answer to the technical issues.

Number of RF VDL2 networks per Service area

An RF VDL2 network is composed of a set of ground stations connected to the same management system and operated by a single entity, with the function to provide VDL2 coverage in a well-defined Service area

Two different kinds of RF VDL2 network are defined as the first factors to identify a model

- **Multiple:** where RF VDL2 ground stations, providing the services in the same Service area, are managed and operated by more than one separated entity.
- **Single:** where RF VDL2 ground stations, providing the services in a Service area are managed and operated by a single entity.

Factor 1	VDL RF operating Networks (on a Service area)	Target
	MULTIPLE	
	SINGLE	Technically preferred

The following rationale assigns a technical preference for the **Single RF VDL2 network**:

- **Full traffic control over the network:** the single RF-VDL network provider will have all the information for the overall management and traffic loads of the services
- **Reduced CSP IoP issues:** in a multiple RF-VDL network deployment scenario, the number and type of interfaces between different CSPs will increase and need to be addressed case by case.
- **Less overlapping areas:** with a single RF-VDL network design it will be possible to maintain to the minimum the overlapping coverage for the same area, based only on the real redundancy/resilience requirements.
- **Better VGS distribution:** in a single RF-VDL network the number and the location of the VGS could be optimised, reducing also the hidden terminal problem.
- **Dual Language capability:** with a single RF-VDL network it will be effective to adopt new technologies as VGS with dual language capability, i.e. to provide both GSIFs inside the same RF frequency
- **Increase RF capacity on shared channels:** with a multiple RF-VDL network environment the capacity of shared (by more than one CSP) channels must be managed with a larger margin of error, which causes inefficiency. In particular, this is true, in any configuration, for CSC

VDL2 Frequency Licensing assignment

VDL Frequency Licensing assignment is the way by which the use of the VDL frequencies is regulated by the network authority.

Two different types of frequency assignment are defined as the second factor to identify the model

- **Common:** in a Service area, ground stations operating on a specific VDL Frequency in that area are managed by more than one Frequency Licensee with separate RF networks.
- **Reserved:** in a Service area, all ground stations operating on a specific VDL frequency in that area are under the responsibility of one unique Frequency Licensee who is responsible for managing the traffic on that RF network.

Furthermore, two different technologies can be used by VGS:

- **"Single DSP ID System"** means that any VGS broadcasts the ID of only a single DSP in its GSIF frames on the RF channel.
- **"Dual DSP ID System"** means that any VGS broadcasts the IDs of multiple DSPs in its GSIF frames on the RF channel.

	VDL RF Frequency Use	Target
Factor 2	COMMON	
	RESERVED – Single DSP ID System	
	RESERVED – Dual DSP ID System	Technically preferred

The rationale to assign the technical preference on the **reserved** assignment using dual DSP ID systems are fully explained in the sections related to the "Channel Allocation" and "Load Balancing and Managing" whose results are reported in the table below (from D09).

ITEMS	Common VDL Frequencies	Reserved VDL Frequencies – Single Language	Reserved VDL Frequencies – Dual Language	Preferred
Hidden terminals*	Common frequency operations require multiple CSPs to have RF coverage in the same region. For ENR operations, this will increase the number of hidden terminals. If CSPs are sharing the same RF channel, there will be roughly twice as many ground station radios as when compared with a single CSP. More ground station radio transmissions mean more RF collisions.	As in the case of Reserved frequencies each channel "sees" a single RF Networks, for ENR operations, this will decrease the number of hidden terminals. Less ground station radio transmissions mean less RF collisions	As in the case of Reserved frequencies each channel "sees" a single RF Networks, for ENR operations, this will decrease the number of hidden terminals. Less ground station radio transmissions mean less RF collisions	Reserved SL Reserved DL
CSMA Threshold	More protocol overhead and hidden terminal transmissions will occur on common frequency. Without sharing RF loading information, the CSPs will not be able to	Reserved frequencies can be operated closer to the RF channel CSMA threshold.	Reserved frequencies can be operated closer to the RF channel CSMA threshold.	Reserved SL Reserved DL

ITEMS	Common VDL Frequencies	Reserved VDL Frequencies – Single Language	Reserved VDL Frequencies – Dual Language	Preferred
	operate as close to the channel RF load threshold.			
ATN Performance Requirements	*** Some CSPs may not be able to commit to meeting customer contractual Service Level Agreements (SLAs) for ATN/CPDLC performance requirements on common alternate VDL frequencies. A primary concern for the CSPs will be problems experienced by one CSP impacting the performance of another CSP and impacting the SLA.	As stated in above paragraph "Reserved and Common VDL Frequencies considerations", Reserved VDL Frequencies allow a major degree of control of the performances on the channel.	As stated in above paragraph "Reserved and Common VDL Frequencies considerations", Reserved VDL Frequencies allow a major degree of control of the performances on the channel.	Reserved SL Reserved DL
Operational impact	1. More RF hardware will be required for ARINC and SITA to operate on common alternate VDL frequencies and provide the same RF capacity 2. Higher impact on recurring operations and maintenance to support the extra RF hardware. 3. New interfaces may be required between CSPs to dynamically share RF loading data. 4. Additional testing and simulation tools will need to be developed and implemented. 5. Additional operations overhead to coordinate shared frequency operations with other CSPs.	6. Less RF hardware will be required for ARINC and SITA to operate on reserved alternate VDL frequencies. 7. No interfaces required between CSPs to dynamically share RF loading data. 8. No additional operations overhead to coordinate common frequency operations with other CSPs.	9. The Dual Language Technology allows to minimise RF hardware with respect to the other configurations. 10. No interfaces required between CSPs to dynamically share RF loading data. 11. No additional operations overhead to coordinate common frequency operations with other CSPs.	Reserved DL
Flexibility	Good degree of flexibility, as it is necessary to add a new channel only when the already operated ones are close to saturation	In the case of 4 alternate available frequencies, it shall be considered what happens when the first single GSIF channel comes to saturation.	Good degree of flexibility, as it is necessary to add a new channel only when the already operated ones are close to saturation	Common Reserved DL.
Scalability	Possible to implement a scalable RF network to best fit the user requirements in different Service areas. In particular, it is possible to start using a "new" available channel just when the already used	Improvement should be achieved in optimizing the overall use of the bandwidth, in the sense that, if the single GSIF channel is used, the need arises for a new channel when the first channel is reaching saturation, even if	Possible to implement a scalable RF network to best fit the user requirements in different Service areas. In particular, it is possible to start using a "new" available channel just when the already used	Common Reserved DL In general, better to use Two-GSIF channels (either Common or

ITEMS	Common VDL Frequencies	Reserved VDL Frequencies – Single Language	Reserved VDL Frequencies – Dual Language	Preferred
	ones are getting saturation. So, in this case, there is a good degree of flexibility of the overall use of available bandwidth.	other channels are in different conditions.	ones are getting saturation. So, in this case, there is a good degree of flexibility of the overall use of available bandwidth.	Reserved VDL Frequencies).
Operational experience	None of the CSPs have any operational experience with sharing VDL alternate frequencies.	** Both SITA and ARINC have been operating VHF DL over multiple reserved VDL frequencies for several decades.	N/A	Reserved SL Reserved DL
Frequen-cies allocation approval (ref. § 2.2)	The ICAO FMG has already authorised VDL frequencies to be shared in Europe. No additional effort is required to get approval to use the VDL frequencies.	Proposed Draft ICAO Allotment Plan to be approved	In the proposed Draft ICAO Allotment Plan to be approved there is a reference to the implementation in a limited area (Italy)	Not technically critical – Waiting for decision
Load Calculation	Difficult to make Load Calculations based on RF traffic on a channel (the most accurate)	Easier to make Load Calculations based on RF traffic on a channel (the most accurate)	Easier to make Load Calculations based on RF traffic on a channel (the most accurate)	Reserved SL Reserved DL
Load Balancing 1	Currently implemented load balancing algorithms have to be improved to be able to work effectively with common VDL frequencies.	Load balancing algorithms already developed and operated.	Load balancing algorithms already developed.	Reserved SL Reserved DL
Load Balancing 2	New interfaces may be required between CSPs to dynamically share RF loading data.	No interfaces needed between CSPs to share RF loading data.	No interfaces needed between CSPs to share RF loading data.	Reserved SL Reserved DL
Load Balancing 3	If available, balancing algorithms can be used with scenarios up to five available frequencies.	As with five frequencies, each alternate channel is used only for one use (APT or ENR) and for one CSP, the balancing algorithms can't be used with scenarios up to five available frequencies.	Available balancing algorithms can be used with scenarios up to five available frequencies.	Reserved DL
Load Manage-ment	Some CSPs will need to develop and implement new RF Load Management algorithms	Load management algorithms already developed and operated.	Load management algorithms already developed.	Reserved SL Reserved DL

* *The ELSA WA1 released the results of an RF Analysis which concluded that "RF issues are driven by the collisions due to the hidden transmitters (mostly VGS or aircraft on the ground)."*

*** Although ACARS and VDL are different protocols and use different modulation schemes, they both use CSMA channel access techniques and the frequency management concepts regarding load distribution across APT and ENR environments are the same.*

**** Examples of issues coming out from sharing alternate VDL frequencies:*

1. *Poor ground station or system performance from one CSP could impact other CSPs performance on the common channel.*
2. *One CSP VDL ground station hand-offs may not be efficient, increasing RF load on the channel.*

3. *One CSP may have equipment impacting performance on another CSP.*
4. *With multiple CSPs operating on the same VDL channel, fault isolation with airframe manufacturers/avionics vendors will be more difficult and take longer.*
5. *CSPs will not be able to operate existing algorithms implemented to enable the VDL channel to be effectively operated close to the RF loading threshold.*

4.5.3.1 RF Network Architecture

Network GSIF advertisement capability

This factor will indicate the capability of the network to provide services (through the GSIF advertisement) inside the same frequency/channel.

Two different capabilities of GSIF on each Frequency announced by each Network (VGS languages) are defined as the third factor to identify the model

- "**One-GSIF channel**" means that all Aircraft (their avionics) will detect just a single DSP ID in the GSIF on a particular RF channel.
- **"Two-GSIF channel"** means that all Aircraft (their avionics) will detect two DSP IDs in the GSIFs on a particular RF channel

	GSIF on each Frequency announced by each Network	Target
Factor 3	One-GSIF	
	Two-GSIF	Technically preferred

The rationale to assign the technical preference on the **Two-GSIF Channel** assignment is fully explained in the sections related to the "Channel Allocation" and "Load Balancing and Managing" whose results are reported in the table above.

Furthermore, the following rationale assigns a technical preference for the **Two-GSIF channel**:

- **Service resilience/availability:** providing to an aircraft the possibility to connect to any CSPs using the same channel will result in an increase of the system availability, giving multiple options to the user without retuning to CSC.
- **RF network optimisation:** using new technologies such as "dual language" VGS could reduce the physical number of radios operating on a channel, with subsequent VGS distribution optimisation and hidden terminal effect reduction.

RF Network Architecture Implementation Solution

The analysis described in the previous section indicates a technical preference for the following combination of characterisation factors:

VDL RF operating Networks in a Service area (Factor 1)	VDL RF Frequency Use (Factor 2)	GSIF on each Frequency announced by each Network (Factor 3)
SINGLE	RESERVED	Two-GSIF

Based on these characterisation factors, the following different models have been identified so far, starting from the technical Options (§ 4.3.1); these models reflect the current architectures operating in Europe, and the network architectures proposed for the short/medium/long term evolution.

Table 10 Network models for transition roadmap (from D09)

MODELS	VDL RF operating Networks	VDL RF Frequency Use	GSIF on each Frequency announced by each Network	Existing today	Note
A	MULTIPLE	COMMON	ONE	YES	Current Central EU model
B	MULTIPLE	RESERVED	ONE	NO	**Target Short term evolution for central EU**
C	SINGLE	RESERVED	TWO	YES	Current model deployed in a limited area*
D	SINGLE	RESERVED	TWO	NO	**Target Long term model for EU VDL network evolution**

*Currently deployed by ENAV on Italian airspace.

The difference between Models C and D is that C is currently deployed in a limited area, while D will be deployed in Service areas (see Annex B). A transition process is therefore also needed between C and D. For further information about the Models, see D09 Chapter 4.3.2.

After having examined all the Options with respect to the topics taken into considerations in the technical analysis, the trade-off conclusions, indicating that Model D should be the Technical Target Solution, can be summarised in a quick way as in the following.

Common VDL Frequency mode has:

- its major Pros in:
    - Possibility to exploit the overall bandwidth in a flexible way (by distributing RF load among the available channels without constraints)
    - Scalability
- and its major Cons in:
    - Difficult to manage the channel load (as different CSPs operate on the same channel without having the complete awareness and control of what happens)

Reserved VDL Frequency mode, using Single DSP ID system, has:

- its major Pros in:
    - More efficiency in using the single channel as reserved frequencies can be operated closer to the CSMA RF Load threshold than common frequencies
    - Possibility to use efficient and already available Balancing algorithms
- and its major Cons in:
    - low level of flexibility (if a channel is “reserved” to a given Licensee, it can’t be used by another one, even if the first is much lower loaded than the other one)
    - low level of scalability (in theory, above a certain level of traffic, in whichever area, at least five channels shall be available since the beginning of the MF deployment)
    - in any case, the CSC shall be managed as a Common VDL Frequency

Reserved VDL Frequency mode, using Dual DSP ID system, in simple terms, puts together the Pros of the two other Options without presenting their Cons:

- its major Pros are:
  - Possibility to exploit the overall bandwidth in a flexible way (by distributing RF load among the available channels without constraints)
  - Scalability
  - More efficiency in using the single channel as reserved frequencies can be operated closer to the CSMA RF Load threshold than common frequencies
  - Possibility to use efficient and already available Balancing algorithms
  - In any case, the CSC is managed as a Reserved VDL Frequency
- its major Cons are:
  - The institutional framework needs to be built (Service areas definition, managing of the transition, etc.).

It is necessary to state that moving from the current operational situation to the single RF network needs some steps that are described in the Transition Roadmap.

Before starting with the deployment phase, a CSP/ANSP Coordination Technical Function should be implemented in order to define all necessary details including:

- to define the Service areas
- to coordinate common to reserved VDL frequency transition plan
- to agree on CSC operations to include RF Loading Thresholds
- to agree on interoperability management (for example, during transition phase, different network architectures, i.e. One-GSIF or Two-GSIF, should be allowed to support VDL multi-frequency operations and ensure seamless transition for avionics between areas implementing different infrastructure types)
- to monitor the RF network capacity levels to anticipate, if necessary, the transition from model B to D.

It shall be noted that the timeline (2025-2030) could be fine-tuned according to the early outcomes provided by the CSP/ANSP Coordination Technical Function.

The Transition Roadmap

Details on Models and Transitions are reported in Annex E. The following only provides an introduction.

Starting from model A and C, already implemented respectively in core Europe and Italy, and named as D the target solution, the following transition roadmap has been identified:

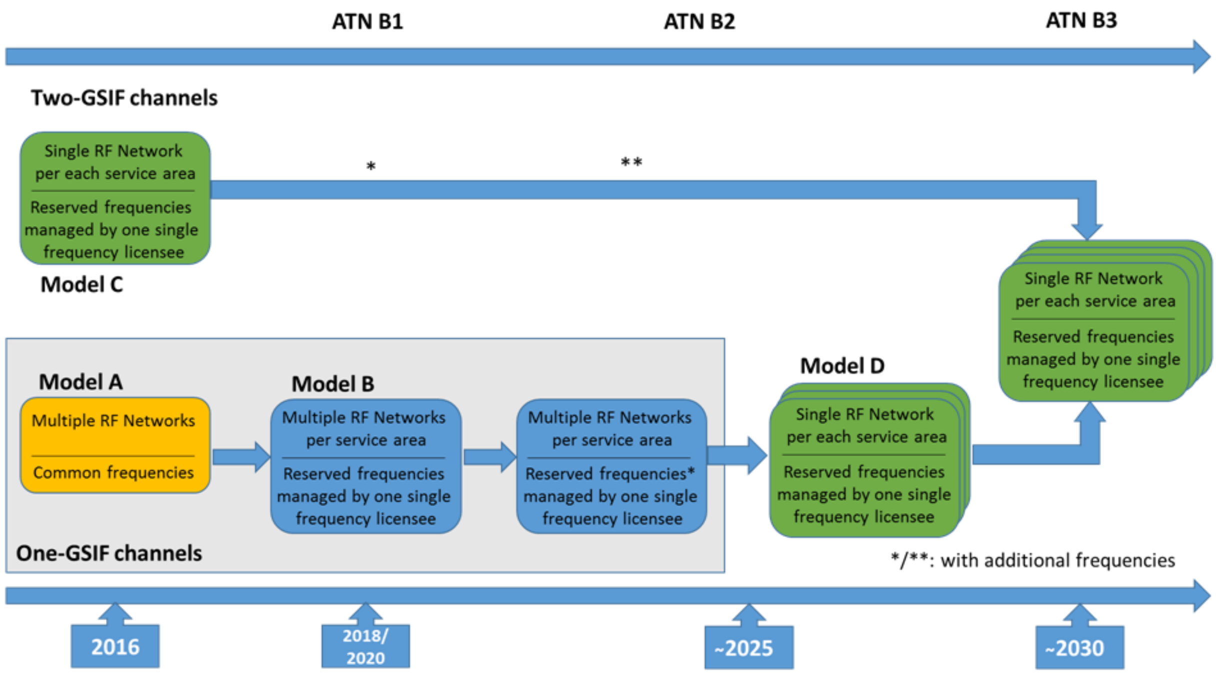


Figure 35 Transition Roadmap

Conclusions: One network per Service area allows for a better design - more efficient capacity (frequency) usage and just enough VGSs to manage traffic densities and for the reduction / avoidance of VGS-caused hidden transmitter effect for shared frequencies (CSC). A Service area can be formed by a group of states, e.g., the FABs.

Channel Allocation

The following findings were identified:

- The use of the CSC as a shared command and control frequency shall be continued.
- The use of reserved alternate VDL frequencies is preferred over the use of common alternate VDL frequencies.
- Different uses of the channels, for example single GSIF or Dual GSIF, can be used during the transition phase to support VDL multi-frequency operations.
- The use of one Dual DSP ID system is preferred over the use of one Single DSP ID system.

The preferred technical solution will be a single RF network for each Service area, using dedicated frequencies to support Dual GSIF.

RF Network technical management

The different models are explained in Annex F . From these, the development model is considered to be the most attractive, because it is linked to the "one RF Network" architecture. For an exhaustive analysis of the various RF Network technical management options, see D09 Ch. 4.1.4

Frequency function assignment

The development of VDL ground stations is determined first by the need to provide the VDL en-route coverage, as requested by the DLS regulation.

In addition, the following implementation requirements must be satisfied:

  - APT coverage for initial logon procedures
  - Airport coverage for AOC traffic (D09 IN2.7).

- APT operations and ENR operations shall be on separate frequencies in Service areas with high traffic levels. In Service areas with low to medium traffic levels, both APT and ENR operations may be supported on a single frequency (D09 IN2.5).
- In deploying MF VDL2 an incremental frequency usage approach shall be followed. RF traffic levels should be the driver to determine the particular usage of a VDL frequency in support of CSC, APT or ENR operations as shown in the below table (D09 IN2.3).

Table 11 Frequency allocation scheme (from D09)

Traffic Level on VDL Frequency	CSC frequency also used for APT and ENR operations	Combined APT/ENR traffic on one alternate reserved VDL frequency	Reserved APT frequency	Reserved ENR frequency
Light to Low	Yes	Yes	Yes	Yes
Low to Medium	No	Yes	Yes	Yes
Medium to High	No	No	Yes	Yes

4.5.4 EASA Action 5 – ELSA Conclusions

Technical assessments of the various MF deployment options have concluded that the best model for MF deployment in Europe is a model, comprising a number of Service areas, where all ground stations operating on VDL frequencies in a given Service area work together under one unique frequency licensee responsible for managing the traffic on the RF network. This model allows the frequency licensee to manage the load balancing in a dynamic way (not to be confused with the concept of “dedicated” frequency model where frequencies are allocated in a static way).

Referring to the identified Service Models, pros and cons of each of them have been studied and finally, ELSA stated that the choice of a Technical Governance model for a particular MF VDL2 infrastructure is a complex topic implying many aspects, most of them not technical. For this reason, the performed analysis did not take to the identification of a preferred model from the pure technical point of view.

Regarding the centralised vs distributed infrastructures, considering that most of currently DLS issues are on RF segment of DL system, the WA2 technical effort was focused on defining the most suitable MF infrastructure at RF level for both single Service area and European level.

The system architecture for each single Service area has been defined: the basic concept of having a single RF network in a defined Service area is likely to be suitable to respond most of the current issues (interferences and hidden terminals).

Then, the identified European architecture is based on “Service areas” approach that, from a pure technical point of view, means a European distributed architecture. This approach reflects for “RF network” the same principle already considered in A6 study and in PENS, in defining ground-ground network architectures. The number of needed Service areas and their composition, as optimum “level of granularity” of the European distributed architecture, shall be defined in the deployment phase (system design) when all technical and non-technical requirements will be available.

4.6 EASA Action 6 - Evaluation of Avionics and Ground End Systems

4.6.1 EASA Action 6 – Recall of the EASA wording

“Avionics supporting multi-frequency should be trialled with instrumented installations. The objective would be to gather metrics on indicators related to the channel technical usage. This would enable the characterisation of the effect of multi frequency on the different ATN and VDL2 layers.

Installations currently having a high level of disconnections and already capable of operating in multi frequency environment should be assessed in a multi-frequency environment. If problems persist, such installations should be instrumented in order to determine the causes of the problems.

For avionics which generate internal failures or resets of connected units, EASA is obliged to act if there are safety concerns. However, reports would be needed in order to be able to justify the issuance of the appropriate corrective action. EASA could potentially undertake a dedicated audit of the airborne parts and appliances that have already been certified to assess continuing compliance with the declared certification basis. Further, the NSAs (National Supervisory Authority) could undertake a review the Declaration of Verification (DOVs) issued by their ANSPs.”

4.6.2 EASA Action 6 – Activities performed by ELSA

Within ELSA several activities have addressed this topic:

- Initial MF deployments have been evaluated, in normal operation and by means of test flights.
- Interoperability testing of avionics has been performed with devices from different manufacturers (AIRBUS, Honeywell, Rockwell) on specific test benches (prepared by ALTYS).
- Potential protocol optimisations have been determined and evaluated in a three phase process.

4.6.3 EASA Action 6 – Findings

4.6.3.1 Initial operational and experimental MF deployed systems

CSPs Multi-Frequency initial implementations are already in place in some parts of Europe, effectively managing the transition of aircraft between alternate VDL frequencies. In addition, experimental systems were implemented and operated in Fiumicino airport, effectively managing the transition of operational aircraft among three VDL frequencies (CSC plus two alternate frequencies). The following two subchapters list the main conclusions obtained after the analysis of related data, provided by ARINC, SITA, ENAV/LEONARDO, and Skyguide. For further details refer to D09, Section 4.2.

4.6.3.1.1 Initial operational MF deployed system

- The analysis of data collected by ARINC, SITA and Skyguide, related to operational flights, have confirmed the performance improvements with the addition of VDL2 alternate channels. The CSC, currently almost congested in high traffic areas, has been partially unloaded. In order to use correctly the CSC (serving as the primary contact, management and recovery channel for the network, as stated by ICAO), the process of deploying new MF compatible avionics shall still go on. In fact, using only one APT frequency, there are still many aircrafts on the ground with older avionics which remain on the CSC and all aircrafts en-route as well.
- Aircraft can be moved on alternate VDL frequencies using FSL or Autotune effectively, so there is no technical assessment to make on the preference to use Autotune or FSL since they both work successfully (but for some avionics versions behaviour is to be further investigated).

- AVLC performances are very good on alternate VDL frequencies as expected.
- Initial MF VDL2 deployment is showing improvement of performance and decrease of PA.

4.6.3.1.2 MF experimental systems

- The ENAV/LEONARDO experimental systems was implemented and operated in Fiumicino airport, effectively managing the transition of operational aircraft among three VDL frequencies (CSC + two alternate frequencies).
- The analysis of data collected, related to operational flights, have confirmed the performance improvements with the addition of VDL2 alternate channels as described in previous paragraph.
- The CSC has been unloaded, coming back to its original function to serve as the primary contact, management and recovery channel for the network (as stated by ICAO)
- The alternate channels worked properly proving also the load managing algorithm effectiveness
- Aircraft could be moved on alternate VDL frequencies using FSL or Autotune effectively, so there is no technical assessment to make on the preference to use Autotune or FSL since they both worked successfully (but for some avionics behaviour to be further investigated, as stated also in WA3).
- AVLC performance were very good on alternate VDL frequencies as expected. Dedicated flight trials for CPDLC (with cooperation of ENAV Flight Inspection Dept. and 31st Wing of Italian Air Force) were performed successfully without PAs and with good performances (for example: RTD).

4.6.3.2 MF Avionics Interoperability Tests

The avionics' MF interoperability tests have allowed covering main MF use cases as follows:

- FSL (Frequency Support List, air and ground)
- GRAIHO (Ground Requested Air Initiated Handover)
- Auto-tune commands included in LE and HO responses
- Air-ground transition (FSL-based)
- Ground-air transition (FSL-based)

The overall test results of the different avionics configuration ("best in class") showed a good support of the tested baseline for the different VDL2 MF mechanisms. Only some minor issues without operational impacts have been identified (see D10, Section 6).

4.6.3.3 Avionics Interoperability Tests

Interoperability tests have been performed with devices from different manufacturers in specific test benches, see D10 Section 6.

The ELSA interoperability tests, with more than 500 variants of tests performed, showed that tested avionics configurations passed almost all the MF tests with only minor issues, not having operational impact (see details below). Some enhancements were identified to clarify the current standard baseline.

Generic findings:

- Avionic HO behaviour: differences between the avionics implementations leading to various levels of reliability in maintaining connectivity. Answering this finding requires a standard clarification, to monitor operational HO performance and to do assessment using simulation in order to clarify implementation guidelines.
- SQP scale not aligned between all tested VDRs (which does not always provide a fair view about the signal quality). Answering this finding requires standard change and reference test bench for VDR qualification.
- X25 reconnect timer is relatively long (up to 3.6 minutes) and could lead to long delayed CPDLC messages and Provider Aborts, if the X25 is unexpectedly cleared by the ground network. Answering this finding requires a standard clarification.
- Airborne frequency scan, based on the aircraft operator's CSP preference, is designed to search for overall VHF (POA or VDL2) connectivity, not specifically VDL2 connectivity (i.e. not connecting to any CSP's ground station having the best VDL2 signal).

  - E.g. switching to a POA frequency of the preferred CSP before a VDL2 frequency of an alternative CSP.
  - E.g. adding alternative DSP to VDL2 PECT could speed up switching between ACSPs.

Answering this finding requires a standard clarification taking into account economic constraints and impacts on aircraft operators.

- Low VDR performance for various VDR products in High CU environment leading to loss and delay of VDL2 frames notifications. Answering this finding requires a standard update in order to add stress tests covering harsh environments.
- Lack of robustness in the VDL2 physical layer detection, leading to loss of the VDL2 burst, if the start of the burst is corrupted due to a collision or unexpected RF noise/event. Answering this finding requires a standard clarification.
- Advanced interoperability tests, showing that following Uplink DM or DISC, the ATN network connection is cleared. Answering this finding requires standard change

Manufacturer specific findings:

- Lack of conformity in VDR implementation for the header FEC correction. This is a non-conformity issue, but according to manufacturer requires standard update.
- VDL2 Link loss management inconsistency. Answering this finding requires standard clarification.
- Some old generation VDRs are not able to decode long multi-frames. This finding is not relevant as no impact on the current network operations.
- Lack of conformity in the VDL2 timer (T1, T3) calculations proportionally to the CU. Answering this finding requires standard clarification.
- Robustness issues, VDR and CMU resets experienced during stress tests. The occurrence probability of such events on the operational network is very low and could happen only if they are intentionally generated. But if experienced, VDR resets may introduce frame losses and delays between aircraft and ground network. These issues have been reported to manufacturers and some fixes have been implemented.
- X25 connection unexpectedly cleared by Airborne System. Only one implementation is concerned, the problem seems to be fixed by manufacturer in the second iteration.
- Uplink VDL2 DM management issue where the airborne systems immediately try to reconnect to the ground station that just sent a DM despite the availability of other active ground stations. This is a minor issue and has a very limited impact on the current network operations.
- IDRP protocol, heterogeneous connection loss management implementations. Answering this finding requires standard clarification.

ID	Finding description	Proposed answer
FIND1	Today's VHF ground network deployment [2.6] & [4] required to support AOC communications, is not necessarily optimized for ATC services.	Some form of a direct answer to these issues is the creation of a technical Pan-coordination body for ground network deployment and management.
FIND16	Avionics SQP scale is not aligned between tested VDRs and is not always providing a fair view about the signal quality	Require standard change and reference test bench
FIND3	Long X25 reconnect timer for Airborne System (up to 3.6 minutes)	Require standard clarification
FIND4	Non-optimized frequency scan for ATN CPDLC	Require standard update
FIND8	VDL2 Link loss management inconsistency (DISC, DM, N2, TG2) (interop)	Require standard clarification *(to be linked with Detect peer loss of communication optimization OPTIM13)*
FIND14	IDRP protocol, heterogeneous connection loss management implementations, Lack of robustness in the airborne X25 M/I bit management (interop)	Require standard clarification
FIND7	Lack of robustness in the VDL2 physical layer detection, leading to loss of the VDL2 burst	Require standard update (Enhancement)
FIND15	Following any Uplink DM or DISC, the ATN network connection is cleared	Require standard change (*to be linked with Detect peer loss of communication optimization OPTIM13*)

Figure 36 D10 Summary of Findings (from D10)

ID	Finding description	Proposed answer	Issue severity & impact on network performance
ISSUE1 (FIND6)	Lack of conformity in the VDR implementation for the header FEC correction	Non-conformity issue, but accordint to manufacturer requires standard clarification	*Low* as the FEC mechanism will allow to recover only minor percentage of the corrupted frames.
ISSUE2 (FIND10)	Lack of conformity in the VDL2 timer (T1, T3) calculations proportionally to the CU (interop)	Minor issue	Not relevant
ISSUE3 (FIND9)	Some VDRs are not able to decode long multi-frames (limited to 8)	Minor issue	Not relevant as no impact on the current network operations
ISSUE4 (FIND13)	Uplink VDL2 DM management issue	Minor issue	Low
ISSUE5 (FIND5)	VDR CUs equal to zero despite the fact that the VDR was notifying a high channel load between 4 and 16 Kbps	Minor issue to be verified by VDR manufacturer for the received signal level	Low or not relevant
ISSUE6	MF switch latency assessment (22.7 seconds) cf. 6.3.2	Minor issue	Low
ISSUE7	CMU finding, first FSL not randomly selected cf. 6.5.2	Manufacturer confimrs that this issue has been fixed in more recent version(not tested in the scope of WA3)	Low
ISSUE8	LCR cause parameter values not set properly cf. 6.5.2	Minor issue	Low or not relevant
ISSUE9 (FIND5)	Low VDR performance in High CU environment leading to loss and delay of VDL2 frames notifications	Testing beyond specification, could require standard enhancement and chaning specification	No impact as resulting from stress tests.
ISSUE10 (FIND11)	Robustness issues, VDR and CMU resets experienced during tests	Stress test not necessarly operational, Issue partially addressed by manufacturers	No impact as resulting from stress tests.

Figure 37 D10 Identified Issues and Analysis (from D10)

4.6.3.4 Network Findings

Several points have been raised and have been investigated with ARINC and SITA about the results from the KPI analysis (see D08, 7.2.2):

- The Number of uplink retries on the ARINC network is above average.

  Conclusion for this higher average is due to ARINC's SREJ handling difference. During the time of congestion, uplink re-tries can go significantly beyond N2. The ground station release schedule date is currently unavailable, but system analysis of a solution has started for this problem. The next ground station release will contain this fix.

- The Number of HO/LE on the ARINC network is above average.

  This topic is tightly related to avionics behaviour. As identified in D08, 7.2.2.3.4, the performance of the avionics on that matter is dependent on their maturity. Investigations have shown that the ARINC network is hosting more "older version" avionics than SITA. This difference makes this specific topic irrelevant for comparison.

- Ground CLEAR issue on ARINC network. MOON logs show some peaks of ground CLEAR-REQUEST during April 2015.

  ARINC examined more a detailed breakdown of the peaks and concluded the peaks are localised issues. A software malfunction can occur at some busy stations causing it not to properly process traffic. Ground CLEAR-REQUEST sent to all aircraft connected to this VGS at the same time can be the result. ARINC has a fix available. GS Deployment is complete as of early February 2016.

- Ground CLEAR Request KPIs (Section 3.2 of document attached in D08, 14.2.1) show that SITA is the main contributor of ground CLEAR Request.

  There are Clears that are normal in the context of handoff (8090), and none impacting to the service. Others are the result of LREF de-sync (mobile SNDCF Clears, which are usually a side effect of N2T1 and Handoff). Others may be Network related or VGS related. Some cases have been identified with multiple aircraft clearing simultaneously by the same VGS. Even if Call Clearing does not mean PA (while PA may be related to Clear in certain cases) this can cause a local increase of traffic in the case of multiple clearing and therefore difficulty for aircraft to reconnect.

- Important difference in terms of DM quantity between ARINC and SITA. On ARINC network there is a lot of uplink DM, on SITA network there is a lot of downlink DM (Section 2.8 of document attached in D08, 14.2.1).

  Uplink DM on ARINC network is directly correlated to the number of retries (which is linked to the SREJ management implementation on ARINC's network).

Downlink DM on SITA side is due to handoff. SITA's understanding is that according to the protocol the aircraft, on receipt of a DM, is supposed to re-establish the link. Some aircraft appear to react incorrectly to the DM and blacklist the ground station instead of re-establishing the link. If aircraft does a HO and passes to another station it will disconnect the station it is leaving. The VGS may still try to send traffic resulting in the aircraft sending back a DM. The CVME[10] will prevent this by advising the previous VGS that the aircraft has successfully HO. Therefore in the first approach a SITA CVME will be accommodating the avionics' shortcoming rather than optimising SITA's DM management. In the second approach the CVME will indeed improve SITA's DM management. This will be optimised with the introduction of the CVME this year. The downlink DM is the normal response from the aircraft saying it has no link available, with no impact on PA by itself.

The detailed graphics associated to the numerous KPIs registered may be found in D08 Annex 4 (Section 14.2.1).

[10] Cf. ARINC631 & ICAO 9776 Manual

4.6.3.5 HO Management

Section 4.3.3 already presented the impact of Handovers on the data traffic. It also showed that “best in class” avionics are managing the HO better that the “typical” ones.

4.6.3.6 Protocol Optimisations

The following text has been adapted from D10, Section 5. Protocol optimisations have been determined in a multiphase process with the involvement of several ELSA partners.

The first phase was led by AIRBUS and consisted on inviting the ELSA partners (i.e. avionics manufactures and ACSPs) to send their optimisation suggestions individually to AIRBUS. Once done, all suggestions were consolidated and several joint technical workshops were organised in order to explain and discuss the proposals. Following the workshops an electronic voting was organised in order to select ten suggestions for further evaluation.

The second phase consists of detailing the selected suggestions in the context of simulation in order to identify the related KPIs. In addition to that each optimisation is simulated individually in order to assess the direct impact.

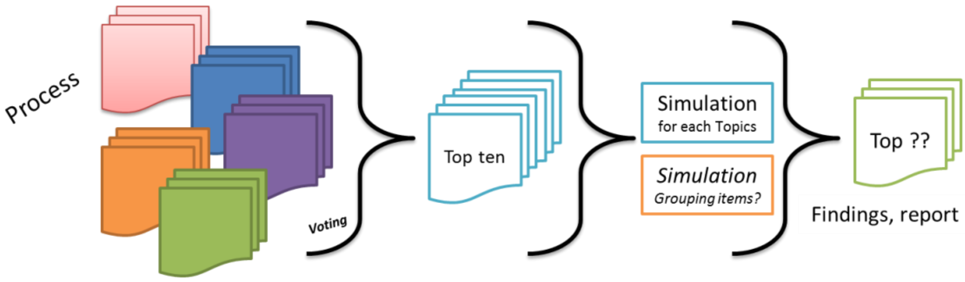


Figure 38 Protocol optimisation process overview (from D10)

The following optimisations were identified to have the most beneficial impact (based on the observed KPI):

Optim10: Non-use of IDRP (detailed in D10, 5.12)

Optim8: Concatenate CPDLC LACK with TP4 ACK (detailed in D10, 5.9)

Optim1: Reduce VDL2 frame size (detailed in D10, 5.3)

No major improvements were found on the following optimisations:

Optim2: Longer ACARS retransmission timers (detailed in D10, 5.4)

Optim3: AVLC T1 computation (detailed in D10, 5.5)

Optim4: AVLC T3 computation (detailed in D10, 5.6)

Optim6: Reduce GSIF (detailed in D10, 5.8)

Optim5: Avoid or reduce short AVLC frames (detailed in D10, 5.7)

The following optimisations produced worse results:

Optim9: Ground RF transmitter power reduction (detailed in D10, 5.11)

Optim7: "p" value in the P-persistent CSMA protocol (detailed in D10, 5.9)

Some optimisations were traffic profile dependent like the Optim14: ATN/AOA prioritizing at ground side (detailed in D10, 5.16).

And, finally two additional topics were studied by technical focus groups within the scope of this sub-activity:

Optim11: Reduce ground ACARS latency (check/link with T2 AVLC) (detailed in D10, 5.13)

Optim13: Detect peer loss of communication (detailed in D10, 5.15)

The outcome is summarised in Figure 39.

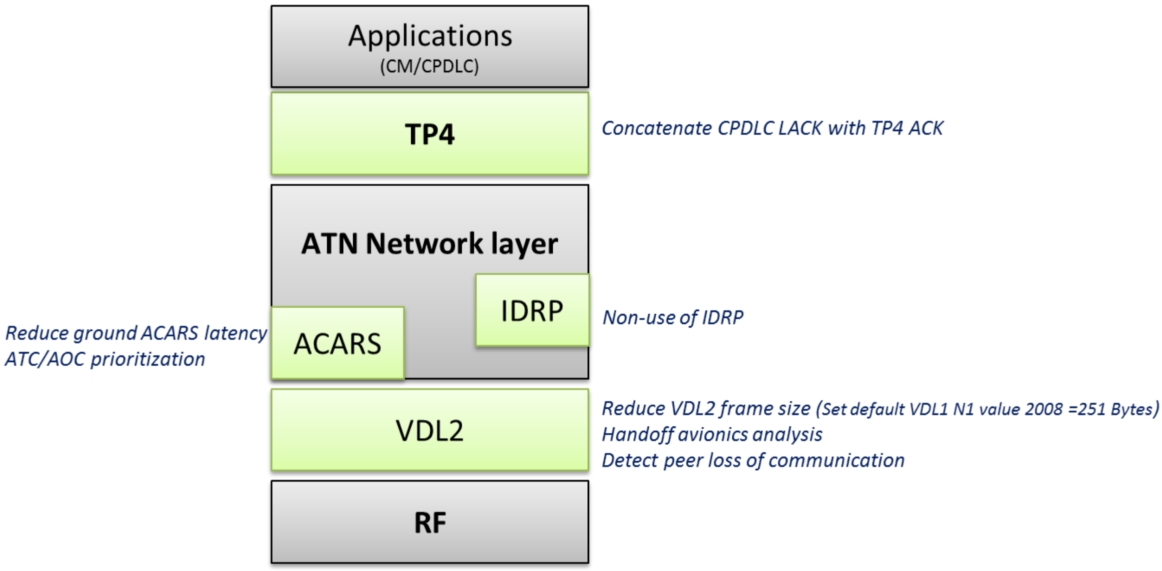


Figure 39 Advantageous optimisation topics (from D10)

4.6.4 EASA Action 6 – ELSA Conclusions

Interoperability tests and analyses of log files revealed that there are issues with system constituents, both avionics and ground systems, and simulations indicate that this combination of issues contribute to the CPDLC performance issues.

The “best in class” avionics however are considered performing sufficiently well also in MF interoperability testing. Therefore equipage compatible with these versions need to be upgraded as soon as possible to leverage the benefits of MF VDL2 deployment. For other equipage “best in class” versions need to be identified following the recommended approach.

A few operational and ground system issues have been analysed and addressed, or are being addressed, by the ELSA partners. Ground system constituents have not been tested in ELSA and further investigations into end-to-end interoperability are needed.

Associated ELSA Recommendations:

- Ground-09: Fix the unbounded retry issue in certain VGSs.
- Ground-10: Fix the Clear Request issue.
- Ground-11: Optimise the Disconnect Mode management.
- Avionics-01: Upgrade of avionics to the “best in class” performance.
- Avionics-02: Update the pilot procedures to avoid unnecessary avionics reset.
- Standards-01: Define and implement an effective datalink end-to-end system certification process (including both ground and air components) and reference material for the ground network infrastructure (MOPS-like).
- Standards-03: Include the selected improvements and clarifications in the relevant standards for MF interoperability.
- NetworkOversight-01: Establish a pan-European Air/Ground Data Link implementing function having appropriate steering responsibilities.

- NetworkOversight-02: Establish a pan-European ATN/VDL2 performance monitoring and spectrum coordination function.
- NetworkOversight-03: Establish/empower a pan-European ATN/VDL2 end-to end certification and oversight function for validating (ground and airborne) sub-systems' acceptability.

▪

5 Summary of Findings

In the preceding Section, ELSA findings have been presented as responses to recommended actions from the EASA report ([1] Section 6). They are summarised below:

1. Ground Infrastructure

- Initial improvements at ground and air level that have been introduced and tested in the context of the ELSA project execution (e.g. early MF deployment, partial aircraft retrofit with upgraded avionics …) have proven to noticeably enhance the performance of the overall system, see 4.6.3.1 and 4.6.3.2.
- Simulations and log file analyses confirmed that today's VHF ground network deployment, which has been initially and mainly deployed to support Airline Operational Control (AOC) communications (for example, by placing a ground station at each terminal), was not deployed in an optimised way to support the Air Traffic Control (ATC) services. In some cases, there was excessive ground station coverage overlap, which increases collisions from hidden terminal transmissions. In other cases, there may have been areas of limited RF coverage, resulting from the incomplete deployment of the VDL ground station infrastructure, which created unexpected aircraft behaviours for the selection of ground stations. These situations were complicated by the lack of coordination between the CSPs that are sharing the CSC – see 4.1.3.1. Linked to recommendations Ground-01, Ground-02, Ground-03, Ground-04, Ground-05 and NetworkOversight-01.
- Technical assessments of the various MF deployment options have concluded that the best model for MF deployment in Europe is a model where all ground stations operating on VDL frequencies in a given Service area work together under one unique frequency licensee responsible for managing the traffic on the RF network. This model allows the frequency licensee to manage the load balancing in a dynamic way (not to be confused with the concept of "dedicated" frequency model where frequencies are allocated in a static way) – see 4.1.3.2. Linked to recommendations Ground-08 and NetworkOversight-02.
- Technical assessments have shown that the following MF network topology and channel allocation aspects are important:
    - The use of reserved VDL2 alternate frequencies is preferred over the use of common VDL2 alternate frequencies, because they can be operated closer to the RF load threshold.
    - The addition of a fifth VDL2 frequency is preferred over the current four VDL2 frequency allocation in any network management approach.
    - The use of the CSC as a common command and control frequency shall be continued, but should be utilised for AOC/ATS data only in areas with low traffic levels.
    - In general, airport area and en-route datalink operations should be on separate frequencies in areas with high traffic levels. However, in areas with low to medium traffic levels, both airport area and en-route operations may be supported on a single frequency.
    - The deployment of VDL ground stations should be determined by the need to provide VDL2 en-route coverage, as requested by the DLS regulation. In addition, airport area coverage for initial logon procedures and for AOC traffic must also be provided.

  See 4.1.3.2. Linked to recommendation Ground-08.

2. Level of RF interference for the core European area

- ELSA measurements confirmed that the CSC channel is saturated with a Channel Use above 50% during peak hours over the core European air space.0 It is important to note that besides allocating further channels, gains on the retransmission rate will also improve the capacity usage situation – see 4.2.3.1. Linked to recommendations Ground-02, Ground-06, and Ground-08.
- The uncontrolled hidden transmitter effect (i.e., the uncoordinated ground transmitter activity due to overlapping intra- and inter-CSPs coverage, …) is the main contributor to the RF issues encountered during the project's lifetime, with a mean loss of more than 30% of the frames due to this type of RF interference. Additional interference can occur and the origin can vary from satellite signals to modulated voice, but those types of interferences represent less than 1% of the time – see 4.2.3.2. Linked to recommendations Ground-01, NetworkOversight-03, and Ground-07.

3. Management of “hot spots”

- The current single frequency VGS deployment leads to areas with ineffective avionics’ handover behaviour (impacting the overall performance) – see 4.3.3.1 and 4.3.3.2. Linked to recommendation Ground-03.
- ELSA has shown that “typical” avionics are using 18% of the ENR channel capacity only for HO, but monitoring of “best in class” avionics has shown that these are managing the HO more efficiently – see 4.3.3.3. Linked to recommendation Avionics-01.
- Avionics suppliers shared the main principles for handover management. A detailed study was conducted by avionics partners in order to analyse the main reasons behind aircraft handovers. In congested areas (covered by many VGSs), or areas where there was a lack of coverage, the number of handovers increased dramatically for all avionics configurations. In addition, the interoperability tests identified differences between avionics implementations which led to various levels of performance in maintaining connectivity. These differences of implementation are driven by the flexibility of the guidelines defined in the current standards – see 4.3.3.4. Linked to recommendation Standards-02.

4. Concurrent management of AOC and ATN data traffic

- The sharing of channel usage between AOC and ATC contributes to the overall congestion of the frequency (mostly at the airport level), even though it is not the main contributor to the ATS problem – see 4.4.3. Linked to recommendations Ground-05 and Ground-07.
- The current CPDLC traffic represents only a low percentage of the overall ATN traffic observed: the link maintenance constitutes significant overhead on the capacity usage. This ratio is nevertheless not at all representative of the nominal use of the CPDLC service (as of today, more than 4500 aircraft VDL2 equipped establish ATN connectivity with ground systems, while very few of them actually make operational use of CPDLC) – see 4.4.3.1.

5. Management of air/ground communication service provision (distributed versus centralised)

- ELSA performed a technical analysis of the existing approaches to network management. Different ground RF network architectures can be described by a combination of three factors:
    - Number of different RF networks (operated by different providers) in the same Service area.
    - Type of frequency licensing (or allotment) used for the VDL2 channels.
    - Type of GSIF advertisement operated on each channel – with one-GSIF either ARINC or SITA is accepted, with two-GSIF both are accepted.

  A trade-off analysis has been conducted by considering the behaviour of the options, identifying which of them guarantees the best answer to the technical issues. The model ELSA determined as the best option for the multi-frequency network implementation is:

    - A single RF network is providing all VDL2 data link services in a Service area (areas homogeneous in terms of operational and technical needs, identical with FABs or new similar entities);
    - Alternate frequencies are reserved frequencies, licensed to only one operator in a Service area;
    - Two-GSIF channels are used, meaning all users can be accepted on the same network.

  A transition roadmap has been provided with three milestones defined as short, medium and long term from the current DLS implementation status to the identified target technical solution. These milestones have been identified according to the introduction of B1, B2 and B3 DLS as currently foreseen – see 4.5.3. Linked to recommendation Ground-08. Further technical solution aspects are described in D09 [7], for example load management (D09, Section 4.1.3) and interoperability between CSP networks (D09, Section 4.1.6). Network management details are provided in Annex F .
- In general, different network architectures, for example one RF network with two DSP IDs or two overlapping RF networks with one DSP ID per network, can be used during the transition phase to support VDL2 multi-frequency operations – see 4.5.3.

6. Avionics/ground end systems

- The project has identified “best in class” avionics configurations, which are considered as the set of airborne equipment necessary and sufficient to comply with the ATN/VDL2 performance expectations – see 4.6.3.2 and 4.6.3.5. Linked to recommendation Avionics-01.
- The interoperability tests, with more than 500 variants of tests performed, showed that “best in class” avionics configurations passed the MF tests. The following additional results have been noted:
    - A few minor MF functionality issues without operational impact have been found.
    - Some MF interoperability improvements and clarifications for the relevant standards have been identified.

  See 4.6.3.3. Linked to recommendations Avionics-01, Standards-01, Standards-02 and Standards-03.
- Issues with ground sub-systems have been identified. Several of these issues have already been fixed during the project’s lifetime; others have been noted for a follow-up – see 4.6.3.4. Linked to recommendations Ground-09, Ground-10 and Ground-11.
- Some flight crew operating procedures have suggested reset of the on-board equipment when facing CPDLC issues. This reset has proven many times to increase the instability of the link instead of solving the temporary issue – Linked to recommendation Avionics-02.
- Several protocol optimisations were identified leading to capacity gain by reducing the number of messages exchanged – see 4.6.3.6. Linked to recommendation Standards-02.

6 Recommendations

ELSA findings, as presented in Section 4 and summarised in Section 5, have been consolidated from the technical ELSA reports D08 [6], D09 [7] and D10 [8] to develop clear and actionable recommendations to recover to an acceptable ATN/VDL2 datalink situation. The following ELSA recommendations which address the identified findings have also been consolidated from the technical ELSA reports D08 [6], D09 [7] and D10 [8]. The recommendations are grouped per domain, addressing Ground (Network), Avionics, Standardisation and Network Implementation and Oversight. Recommendations are identified, consequently, as “Ground-x”, “Avionics-x”, “Standardisation-x” and “NetworkOversight-x”, respectively.

The recommendations are presented in the following Sub-Sections. Their implementation will lead, if addressed in a coordinated way by all stakeholders, to an ATN/VDL2 system that provides acceptable performance to support the full deployment of ATN B1 CPDLC service in the European airspace. As an example, best in class avionics have demonstrated that they can provide less than 4 PAs per 100h CPDLC usage (compared to an average rate of 20 PAs per 100h of CPDLC as measured during ELSA project), without other ELSA recommendations being deployed.

The recommendations proposed for implementation will further provide sufficient ATN/VDL2 capacity to support the deployment of ATS data link services in the European airspace until future generation network and communication means are available ((e.g. ATN/IPS, AeroMACS, future SATCOM and/or LDACS).

The implementation of the recommendations should be addressed as soon as possible (or have already been addressed within the ELSA project). A proposed scheduling of these recommendations is depicted in Figure 40, however the exact implementation will have to be elaborated in a second step.

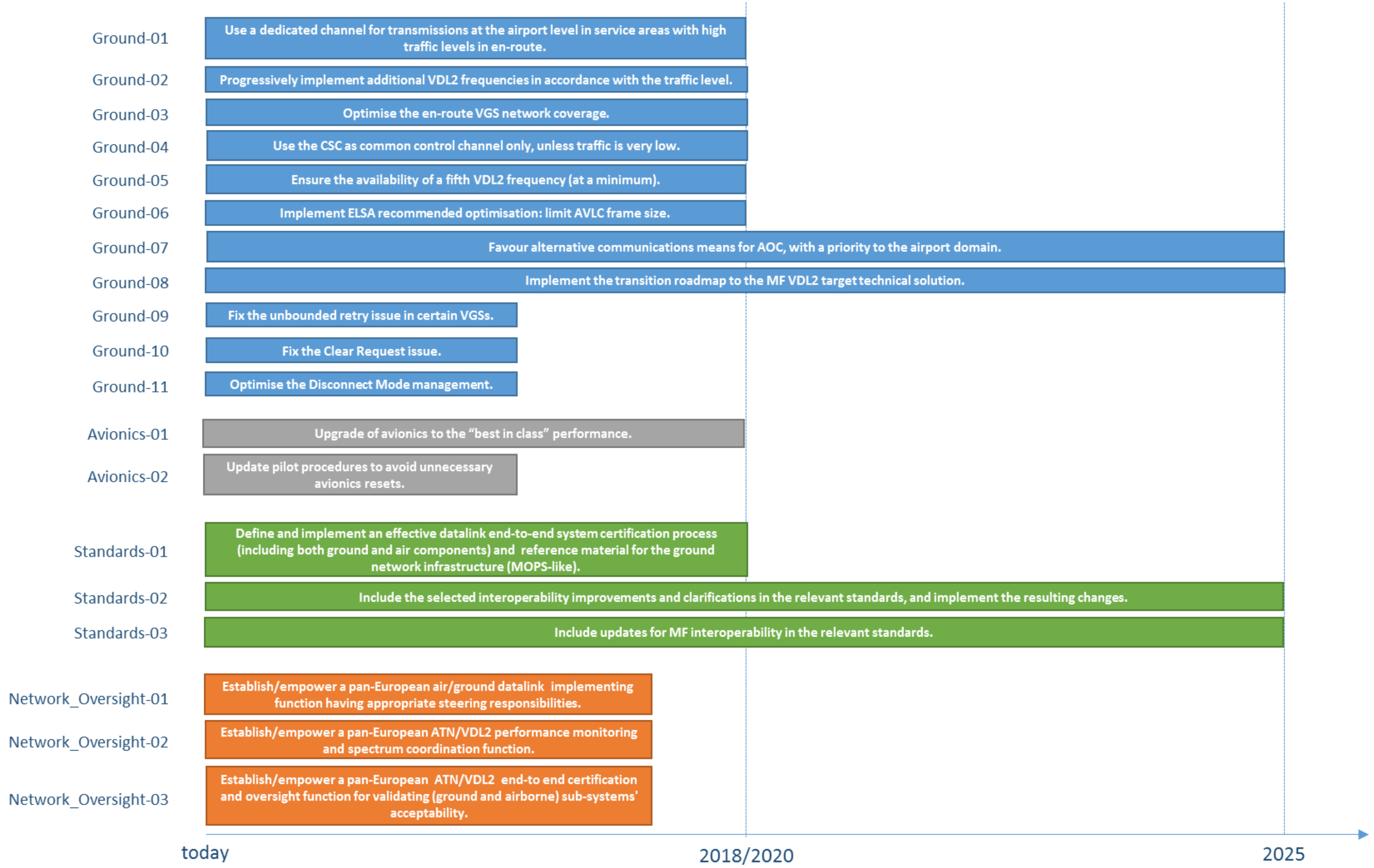


Figure 40 ELSA Recommendations Overview

6.1 Ground Network

The first implementation of a multi-frequency network is already underway. ELSA has identified a target MF deployment solution and the transition roadmap to reach it, which can significantly improve performance, as noted below. It has to be noted that in the beginning, there are still separate networks operated by the current service providers.

Ground-01: Use a dedicated channel for transmissions at the airport in areas with high traffic levels in en-route.
Associated findings: Data collections during revenue flights but also during tests performed by the various partners have shown that most of the PA (75% during ELSA batch 1) have an origin related to RF. The additional RF recordings analyses have shown that more than 30% of the frames transmitted to ENR are lost due to hidden collisions. This rate is much higher than the expectation showing that, even if this is a p-CSMA known phenomenon, it is uncontrolled today. The study performed during ELSA has also shown a direct relationship between the frames loss and the high density zones (either in terms of ground deployment or traffic density). The loss of frames is reaching a 45-50% rate over some areas. ELSA data analyses have shown that overall the AOA traffic is not dominant in en-route: the AOA traffic represents less than 30% of the ENR traffic. In addition, 60% of the traffic is coming from the ground with roughly 20% of it being dedicated to communication between the ground and aircraft on ground. Nevertheless the long term view in terms of capacity usage has to be taken into account. 70% of the traffic for aircraft on the ground is AOA only. If it is anticipated that the AOA traffic can be offloaded gradually, thus the capacity usage in the airport area will decrease and then the partitioning would be reviewed to have frequencies reallocated e.g. to both airport area and en-route. The assessment of the impact on en-route has to happen simultaneously with the deployment of airport area frequencies.
Action: Use a dedicated channel for transmissions at the airport in areas with high traffic levels in en-route. At all major European airports, alternate frequencies need to be deployed to separate the en-route data traffic from the airport data traffic. See Annex G.2 for current short term deployment plans.
Gain: ELSA activities have shown two important findings that are linked: The "hidden transmitters" effect is the main contributing factor to the uplinks collisions: More than 30% of frames are lost due to it, causing a high number of retransmissions with adverse effects on channel load. Having dedicated channels will reduce the impact of the hidden transmitter effect. Furthermore, having a dedicated frequency for the communications at the airport level will remove 20% of the traffic on the en-route frequency and will therefore decrease the rate of collisions in en-route, decreasing retransmissions and therefore the channel utilisation.
Linked to: n/a
Timeframe: To be considered during the already on-going MF deployment and completed until 2020, then continue accordingly.

Ground-02: Progressively implement additional VDL2 frequencies in accordance with the traffic level.

Associated findings: It is technically inefficient to deploy frequencies uniformly. It is therefore needed to manage overall an incremental frequency usage based on the needs of the network.

The deployment of additional frequencies should be firstly based on the density of the traffic to be covered. There is therefore a notion of capacity that needs to be integrated in the dimensioning of the frequency allocation.

Action: Follow an incremental frequency usage approach when deploying MF VDL2. Use RF traffic levels as the driver to determine the particular usage of a VDL frequency in support of CSC, APT and ENR operations as shown in the following table:

Traffic Level on VDL Frequency	CSC frequency also used for APT and ENR operations	Combined APT/ENR traffic on one alternate reserved VDL frequency	Reserved APT frequency	Reserved ENR frequency
Light to Low	Yes	Yes	Yes	Yes
Low to Medium	No	Yes	Yes	Yes
Medium to High	No	No	Yes	Yes

NOTE: the definition of light/low/medium/high traffic shall be agreed.

Gain: Scalability of capacity, allocate resources only where and when needed.

Linked to: Ground-06, NetworkOversight-01

Timeframe: From today (2016) to 2020, then continue accordingly.

Ground-03: Optimise the en-route VGS network coverage.

Associated findings: In addition to the identification of hidden transmitter effect as a major contributor to PAs, ELSA airborne recordings have shown that 30% of the airborne traffic is coming from managing the VDL2 connection. Moreover the HO maps produced during ELSA are showing that the amount of HO managed at the avionics level is dependent not only of the algorithms set-up on board but also of the environmental aspects, i.e. the VGS distribution.

Therefore particular care shall be taken on the design of the ENR VGS distribution. The real operational VGS coverage as well as SQP and transmission success probability are items that need be taken into account to support the guidelines for network deployment (with inputs from ELSA activity outcomes).

Once the main traffic contributor can be moved to an alternate frequency, it is mandatory to minimise RF coverage overlaps for VGS dedicated to the ENR phase while ensuring full coverage of the ENR airspace. Design recommendation include activities related to specific RF coverage studies to be

performed by CSPs with the goal of a necessary (high enough SQP) and sufficient (limited overlapping) ENR network coverage. This recommendation could be achieved by optimising the current network through MF deployment and by optimising the placement of individual VGSs. Further details are provided in Section 4 of D10.
Action: Implement (MF) network upgrades based on the commonly agreed ELSA deployment strategy: The VGS multi-frequency deployment strategy for the long term (2030) has been developed (as an overall foreseen coverage) allocating the CSC and the alternate (for specific functions - APT or ENR coverage) VDL2 channels, starting from the current deployment and passing through the short (2018) and medium (2025) terms. The deployment strategy is provided in Annex G . NOTE: The scenarios reported in Annex G are representative of the possible strategies of the CSPs. They indicate some guidelines in order to deploy the VDL2 RF networks, but, obviously the actual implementation of those networks is dependent on a number of variables (both technical and not) that are normally taken into account only in the design phase. Therefore, the proposed allocation shall not be considered as a commitment for deployment.
Gain: 30% of the frames transmitted to ENR are lost due to hidden transmitters. Optimised en-route VGS coverage will lead to an improvement of the ENR channel utilisation level. In addition, the deployment plan will lead to an AOA services coverage improvement.
Linked to: Ground-01, Ground-02, Ground-04, Ground-06 and Ground-08.
Timeframe: Has to be addressed as soon as possible and completed for 2020, then incrementally to meet implementation milestones.

Ground-04: Use the CSC as common control channel only, unless traffic level is very low.
Associated findings: In a “reserved VDL frequency” scenario, the CSC should keep its function/role so that the avionics can connect/reconnect properly to the network in case of issues. Therefore the CSC should remain on a common (shared) frequency, be kept loaded as low as possible and be used as much as possible only for command/control data exchange and not for AOC/ATS information data exchange – with the possible exception of airspace with low traffic level where the CSC can be used to avoid unnecessary deployment of additional frequencies.
Action: The use of the CSC as a shared command and control frequency shall be continued. Therefore, aircraft shall be moved off of the CSC to alternate VDL frequencies whenever practical. However, in Service areas with low traffic levels, the CSC may be the only VDL channel needed. To that end, coordination will be performed by the air/ground datalink implementing function, and the monitoring is to be performed by the monitoring and spectrum coordination function.
Gain: Improvement of efficiency in RF use and safety.
Linked to: NetworkOversight-01, NetworkOversight-02
Timeframe: To be adopted as soon as possible and completed by 2020.

Ground-05: Implement ELSA recommended protocol optimisation: limit the AVLC frame size.
Associated findings: In 2015, the AOA protocol is the main source of long AVLC frames. The side effect of transmitting long AVLC frames is the channel occupancy induced in case of retransmission, and the increase of the probability of uplink collisions. That is why very long AVLC frames should be avoided mainly when the overall channel occupancy is high. ELSA simulations conclude that an optimisation is possible. This can be done through a reduction of the AOA frame size (by reducing the AVLC N1 parameter to match the average ATN frame size while still allowing an AVLC frame to contain one AOA packet (i.e. one ACARS blck)). The proposed value for N1 is 251 bytes. This is referred to as OPTIM1, in D10, and details can be found in D10 Section 5.3. However, SITA traffic measurements indicate that long frames account only for 5% of the AVLC frames, so verification is needed to confirm the efficiency of this approach. This has no impact on the avionics.
Action: Limit the AVLC frame size in ground networks (by reducing the AVLC N1 parameter to match the average ATN frame size while still allowing an AVLC frame to contain one AOA packet (i.e. one ACARS block)) – a protocol optimisation considered to be low effort. To be monitored by the implementing function.
Gain: Higher probability for successful transmissions, and therefore, increased VDL2 link robustness.
Linked to: NetworkOversight-01
Timeframe: As soon as possible – can also be implemented incrementally. To be completed by 2020.

Ground-06: Ensure the availability of a fifth VDL2 frequency (at a minimum).
Associated findings: The discussions on the traffic and the load of frequencies are leading to the overall network capacity assessment. The current plan is to have four VDL2 frequencies in Europe, but the use of a fifth frequency is already being discussed in the FMG. The one additional frequency is a must to meet future VDL2 needs: The SJU Capacity Study released in 2015 [10] shows that any four frequencies scenario cannot sustain the current traffic forecast. Obviously, in the future, the possibility of having more than five frequencies is recommended. The monitoring and spectrum coordination function (NetworkOversight-02) will further coordinate channel allocations and monitoring.
Action: Independent of the MF deployment approach chosen, the addition of the fifth VDL frequency over the current four VDL frequency allocation shall be requested at ICAO FMG allotment plan level by the European state representation to ICAO.
Gain: Achieve a sufficient level of RF capacity.
Linked to: NetworkOversight-02
Timeframe: To be addressed as soon as possible for 2020 implementation.

Ground-07: Favour alternative communications means for AOC, with a priority to the airport domain.
Associated findings: ELSA activities have shown that 70% of the capacity used by aircraft on the ground is AOA traffic. They have also identified that there is a need to favour the split of ENR and APT frequencies to minimise the level of interference within the system and the dominant issue which is uncontrolled hidden transmitters effect. If we master this unwanted effect, we will obtain a gain in overall capacity. MF deployment recommendations are driven by the fact that the airport communications are impacting the en-route ones. One of the statistic shows that 70% of the communications from aircraft on ground is related to AOC. New communications means (as already discussed) for AOC at the airport level will enable to offload the frequency dedicated to airport communications. Once the load of such frequency will be sufficiently offloaded, it would therefore be possible to reallocate frequencies to both ENR and APT and to gain capacity of the overall system (taking into account that such a change will have to guarantee necessary and sufficient ENR coverage).
Action: Advance the implementation and use of alternative AOC communication means (e.g. Wi-Fi, cellular, AeroMACS). Consider current and foreseen usage levels in VDL2 deployment planning.
Gain: Significant improvement of the ATN/VDL2 capacity for ATS.
Link to: NetworkOversight-01
Timeframe: From today until 2025.

Ground-08: Implement the MF VDL2 target technical solution: in each Service area, one single RF network that operates reserved VDL frequencies supporting two-GSIF channels.
Associated findings: Technical assessments of the various MF deployment options have concluded that the best model for MF deployment in Europe is a model, comprising a number of Service areas, where all ground stations operating on VDL frequencies in a given Service area work together under one unique frequency licensee responsible for managing the traffic on the RF network. This model allows the frequency licensee to manage the load balancing in a dynamic way (not to be confused with the concept of “dedicated” frequency model where frequencies are allocated in a static way). The definition of the MF target solution has been driven by the fact that reserved VDL frequencies can be operated closer to the CSMA RF load threshold than common VDL frequencies. Stability and performance are guaranteed at higher level in a “reserved” mode than in a “common” one, as in the latter case there is competition between services and infrastructure; this competition does not exist in the “reserved” mode. Therefore the use of reserved alternate VDL frequencies is preferred over the use of common alternate VDL frequencies. The fact that reserved VDL frequencies are to be technically favoured can be answered on a technical basis by two types of infrastructures: • Combination of one RF network dedicated to aircraft connecting to ATN through SITA GSIF broadcast and one RF network dedicated to aircraft connecting to ATN through ARINC GSIF broadcast.

- One single RF network broadcasting both ARINC and SITA GSIFs.

Then, different uses of the channels, either one-GSIF or two-GSIF channels, can be used to support VDL multi-frequency operations. However, the capacity of one single RF network using dual DSP ID system (able to manage two-GSIF channels) will be, in time, better than split ones: If the networks' loadings are unbalanced, it is possible that one network will be saturated prior to the other one.

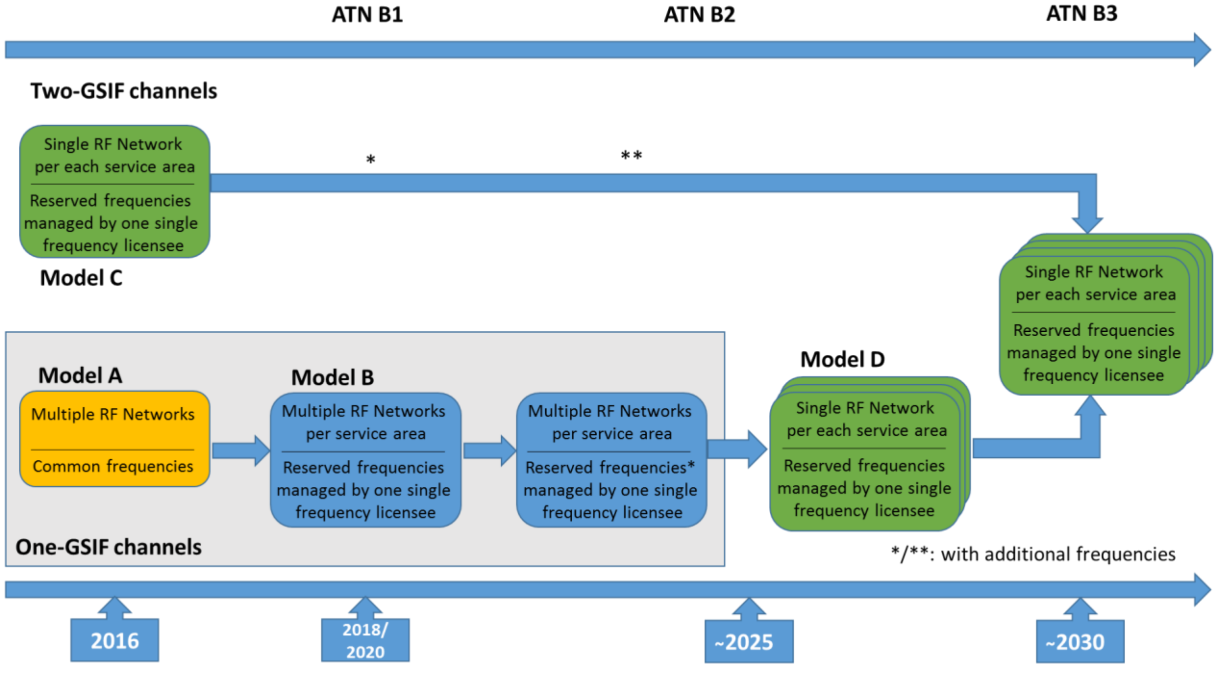
ELSA has identified the best option for MF deployment that constitutes the Target Technical Solution: the implementation, in each defined Service area, of one single RF Network operating reserved VDL frequencies to support a two-GSIF channel (see Annex D).

Of course, that implementation will require planning and coordination across the Service areas. The choice of how the European airspace has to be organised into Service areas (see Annex B) will have to be assessed in the deployment phase.

Action: Implement the MF VLD2 Target Technical Solution: in each Service area, one single RF network that operates reserved VDL frequencies supporting two-GSIF channels. This Target Technical Solution shall be implemented in the long term. The transition from the current situation to the full deployment of the target solution shall be conveniently addressed under coordination of the implementing function. Some of the tasks that have to be executed are:

- define the Service areas (see Annex B);
- coordinate the common to reserved VDL frequency transition plan;
- agree on CSC operations to include RF Loading Thresholds;
- agree on interoperability management.

A Transition Roadmap has been provided from the current DLS implementation status to the identified target DLS solution (a stepwise approach has been followed and the indicative timeline has been set with three milestones defined as short, medium and long term. These milestones have been identified according to the introduction of ATN/B1, ATN/B2 and ATN/B3 DLS as currently planned):



In the Transition Roadmap also the main activities to pass from one model to another have been identified. Furthermore, the interoperability scenarios between different VLD2 RF networks have been studied for CSP boundary operations indicating the mechanism to manage the frequency changes. ELSA has assessed the Target Technical Solution up to 2030. In any case, monitoring is needed at the European level, by the monitoring and spectrum coordination function: • to deploy the identified solution in the most efficient way, exploiting its scalability; • to provide early detection of possible needs of additional frequencies, to manage the frequency request process. Further details of the transition roadmap are provided in Annex E .
Gain: Improvement of capacity and efficiency in RF use (reduction of hidden terminals effects, balanced channel use, etc.).
Linked to: NetworkOversight-01, NetworkOversight-02
Timeframe: From today to 2025.

Ground-09: Fix the unbounded retry issue in certain VGSs.
Associated findings: During revenue flight data collection it has been detected on the ARINC network that in some cases the VGS N2 retry value was unbounded. This is leading to unnecessary loading of the channel (many exchanges between air and ground) and also to maintaining a non-optimal air/ground link that can lead to a PA.
Action: Fix the unbounded retry issue in the next ground station release (ARINC is already planning it)
Gain: A reduced retransmission rate on ARINC network leading to better N2 and DM performance.
Linked to: n/a.
Timeframe: To be completed as soon as possible.

Ground-10: Fix the Clear Request issue.
Associated findings: ELSA airborne recordings have shown a high number of Clear Requests sent by the networks, indicating a problem of the system in certain situations or a malfunctioning of the system at VGS level, respectively.
Action: Fix the Clear Request issue: For SITA, a new release has already been deployed which does not show Clears due to VGS malfunctions. The Clears that are remaining are mainly SNDCF related Clears, due primarily to LREF desync and high level of handovers. To be verified through monitoring. In case of ARINC, a fix is available and deployment is complete as of early Feb 2016.
Gain: Avoids that multiple Clear Requests are sent simultaneously to all aircraft connected to a VGS following a ground software issue. This would avoid creating sudden hot spots of aircraft trying to

reconnect to the network.
Linked to: n/a
Timeframe: Already addressed. Closed for ARINC; SITA to close as soon as possible.

Ground-11: Optimise the Disconnect Mode management.
Associated findings: ELSA airborne recordings have shown that the number of Disconnect Mode on downlink was significantly higher on SITA network. An optimisation has been announced by SITA to enhance the behaviour of its network.
Action: Optimise the Disconnect Mode management. The introduction of a frequency management system will optimise the DM management.
Gain: Will avoid unnecessary exchanges between the ground and the aircraft.
Linked to: n/a
Timeframe: 2016

6.2 Avionics

Recommendations addressing Avionics and their operation are addressed below.

Avionics-01: Upgrade of avionics to the "best in class" performance.

Associated findings: The performance differs between avionics versions and this has an impact on network operation (see for example HO performance in Section 4.3.3 and the Multi-Frequency issues mentioned below). In the years leading up to ELSA, significant effort has already been spent by aircraft & avionics manufacturers to address many issues. This led to the development of upgrades of avionics to enhance VDL2 performance; however harmonisation of avionics performance is needed to improve network performance.
 	
Within the ELSA project, the interoperability testing (including MF functionality) in combination with in-service monitoring of AIRBUS, Honeywell and Rockwell configurations have resulted in the identification of "best in class" products. These configurations passed the interoperability tests and have demonstrated a significant improvement in terms of performance during in-service monitoring.
 	
The interoperability test methodology used to assess the "best in class" performance covered many layers (refer to Annex C for details). The layers covered were:
 	
- VDL2 level
    ○ VDL2 physical layer tests (VDR RF tests) in order to assess the VDR decoding and capture performance in loaded environment (e.g. High CU, High traffic load) and in abnormal situations (e.g. collided PDUs, truncated PDUs)..
    ○ VDL2 Link and Handover management tests in order to assess the handover performance and behaviour.
    ○ VDL2 disconnect management (e.g. DISC, DM, N2)
    ○ VDL2 MF tests based on the "EUROCONTROL VDL2-MF test cases" document covering all the VDL2 MF methodologies - FSL (Frequency Support List, air and ground), GRAIHO (Ground Requested Air Initiated Handover), Auto-tune commands included in LE and HO responses, Air-ground transition (FSL-based), Ground-air transition (FSL-based)
    ○ Verify the VDL frequency scan behaviour and its impact on the end to end performance
- ATN Stack
    ○ X25 handover between CSPSs
    ○ ATN disconnect management (e.g. X25 Clear Request, IDRP loss, ESIS management)
- Application level
    ○ CM/CPDLC communication with ATC centres
    ○ Provider Abort scenarios
    ○ Long delays scenarios
- Protocols timer's, counter's & finite state machine's implementation compliance and

behaviours analysis

The interoperability tests definition have been based on latest versions of standards, i.e. RTCA DO-178B or C whenever applicable, ED-12B, European Commission regulation and the applicable protocol standards (ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual), see Annex C for further details and a list of tests used.

In the scope of ELSA, only the "failed" tests have been deeply analysed. The "best in class" performance was triggered by the operational impact that the failed tests can introduce. It is important to note that some of the tests performed were more stringent than just the level necessary to achieve compliance. This was done in order to stress the equipment and observe its behaviour in a degraded environment.

In addition to these bench tests, the "best in class" performances have been confirmed by the Actual operational behaviour observed on equipped commercial flights indicated by:

1. The PA rate as monitored by EUROCONTROL (below 5 PAs being identified as an operational trigger);
2. The mean timeframe on one VGS (above 5-10 minutes in most of cases).

As an example, on the ARINC network:

- Rockwell VDR920 + CMU900 performance is below 4 PA per 100 hours of CPDLC,
- Honeywell RTA50D + AIRBUS CSB8.3 is below 2.5 PA per 100 hours of CPDLC.

To contribute to the achievement of global ATN/VDL2 performance in the short term, AIRBUS, Honeywell and Rockwell have shared with ELSA the internal implementation aspects (e.g. SW bugs) that have been enhanced to reach these levels of "best in class" performance. Two main types of upgrades have been on the ATN B1 aircraft fleet:

- Upgrades of data link management units, where software bugs have been identified as creating air/ground network interoperability issues:
  - AIRBUS FANS B+ ATSU CSB8 upgrade is mandatory to fix a software bug in the initial version (CSB6) identified as a blocking interoperability issue for VDL2 Multi-Frequency operations.
  - Honeywell upgrade is mandatory because of bug fixes and improvements affecting VDL2 and ATN stack performance, interoperability, and robustness, many of which were identified during test flights in Europe.
  - Rockwell Collins CMU-900 operators should upgrade to CMU Core software in order to fix a software frequency management bug impacting the VDL2 Multi-Frequency operations.

- On board VDR robustness to address saturated VDL2 environment in core domestic Europe: For instance, the VDR deafness issue identified by several avionic suppliers as a blocking issue for VDL2 uplink reception by aircraft in a saturated environment. The behaviour that has been corrected is linked to the capacity of the radio to still "hear" the uplinks, while being in a RF saturated environment.

Note: Some issues related to inaccurate standards or misinterpretations of these were identified but these were assessed and result in no significant impact to the operation of CPDLC. These are listed as part of EASA Action 6 (Section 4.6) within this report.

ELSA has identified a set of CMUs and VDRs reaching "best in class" performance. This list has been added in Annex D so that the "best in class" version should be applied (software upgrade) by the airspace users, when available. These best-in-class upgrades are needed in any case to address the correct operation of MF as it affects e.g. the capability to move to the alternate frequency when requested by the ground station.

For the other avionics configurations, ELSA recommends that the same methodology shall be pursued to ensure demonstration of compliance with the expected performance requirements as detailed above. There is a need to link the "best in class" performance to the certification process specified in Standards-01 with the following specific inputs:
- Equipment qualification:
    ○ CSPs already have specific processes to accept new avionics on their network. Those processes have been gradually enriched over time to address the operational problems that have been faced during the latest years of operations (e.g. deafness, issues associated to loading of the channel…). These tests should be considered as a first means to validate equipment compliance.
    ○ Also, a set of interoperability tests, similar to what has been performed during ELSA, will be an efficient means to get confidence that other avionics configurations can provide ATN/VDL2 performance equivalent to those specifically tested within ELSA. A full list of these tests have been included in Annex C .
- In-service monitoring:
    ○ EUROCONTROL DLS-CRO is maintaining a monitoring of the performance of the different avionics configurations that are deployed and make use of CPDLC. It is important to include service monitoring preliminary to operational approval, which will be approving operational performance before broader deployment (this should be valid as well for major ground upgrades).
 	
These existing processes associated to initial operational monitoring should be evaluated as key inputs within an overall end-to-end system test and certification programme, as specified in the recommendation Standards-01. These two recommendations need to be addressed together. Avionics-01 is dealing with the best-in-class that is available today, and Standards-01 deals with those set of avionics that were not part of the specific testing performed within ELSA. Note that the existing regulatory framework does not cover this today and will have to reflect it in the future.

Actions: ▪ Upgrade of the avionics to the "best in class" versions, when available. This requires that "best in class" versions are being determined for all providers. ▪ Apply the methodology used by ELSA to identify "best in class" performance as a major input to the associated Standards-01 recommendation – meaning, in order to determine the "best in class" versions for all providers, the test bench has to be implemented first.
Gain: Significant performance improvement expected, because avionics have issues that need to be addressed, not only for multi-frequency operation.
Linked to: Standards-01
Timeframe: From 2016 to 2020

Avionics-02: Update the pilot procedures to avoid unnecessary avionics reset.
Associated findings: During flight data collection, some PAs have been "accelerated" by the reset of the ATSU performed by the crew. This specific procedure was defined because of older ATSU versions' behaviour and should be reviewed by the manufacturer.
Action: AIRBUS to adapt the pilot procedures in line with the improvements of the avionics to avoid unnecessary manual reset.

Gain: Avoids adding instability when the communication management is already complex.
Linked to: n/a
Timeframe: 2016

6.3 Standardisation and Compliance

ELSA analyses are showing shortcomings with applicable standards and with compliance to those standards, contributing to the identified issues. From a standards conformance viewpoint the ELSA project was some sort of a safety net that detected issues with avionics and ground systems, but standards and conformance improvement and validation is a closed-loop activity that has to be undertaken.

Solely relying on manufacturers' development processes and on CSPs' assessment processes (SITA VAQ and ARINC AQP) has limitations. In other words, there is a lack of independent testing and validation bodies and implementation rules that mandate the use of such bodies.

ELSA has also shown that testing activities conducted with avionics should be extended to interoperability testing of ground systems.

Another lesson learnt from ELSA activities is that a lack of coordination may lead to inconsistency between various sub-systems (e.g. between air and the ground). This lack of coordination is not the only reason for the inconsistencies; some issues that have been detected are to be considered as corner cases that could not be envisaged on paper. The what-if answers can only be solved by proper modelling at the functional level. There is a need to push for model based verification at the standardisation level to "test" numerous use cases to guarantee that most exchange cases (and potential associated failures) are properly covered.

Even though standard updates take a significant amount of time, some recommendations can be implemented in the short term, since they mainly require coordination through standardisation working groups.

Standards-01: Define and implement an effective datalink end-to-end system certification process (including both ground and air components) and reference material for the ground network infrastructure (MOPS-like).
Associated findings: A major feedback from ELSA is that standards' compliance of subsystems and subsystem interfaces are key. However, some items within the applicable standards have been interpreted differently by services providers, leading to different implementations. This has an impact on the performance of the overall system. A clearer description of the expectations from the various sub-systems, as well as clear interface behaviour has to be established. There is a need to guarantee that any subsystem deployment or introduction will not degrade the overall VDL2 performance. As of today, guidelines for implementation only exist for the avionics. ELSA data collection and analyses have shown that current ground operational systems exhibit different behaviour in some cases. One example is the ground behaviour after detection of peer loss communication: ARINC and SITA networks are not behaving the same, leading to different performance. This recommendation is also linked with the Avionics-01 recommendation. As already stated within Avionics-01, it is recommended that for the other avionics configurations (not covered within ELSA), the same methodology shall be pursued to ensure demonstration of compliance with the expected performance requirements as detailed above. There is a need to link the "best in class" performance

to the certification process with the following input items:

- Equipment qualification:
  - CSPs already have specific processes to accept new avionics on their network. Those processes have been gradually enriched over time to address the operational problems that have been faced during the latest years of operations (e.g. deafness, issues associated to loading of the channel…). These tests should be considered as a first means to validate equipment compliance.
  - Also, a set of interoperability tests, similar to what has been performed during ELSA, will be an efficient means to get confidence that other avionics configurations can provide ATN/VDL2 performance equivalent to those specifically tested within ELSA. A full list of these tests has been included in Annex C.
- In-service monitoring:
  - EUROCONTROL DLS-CRO is maintaining a close monitoring of the performance of the different avionics configurations that are deployed and make use of CPDLC. It is important to include service monitoring preliminary to operational approval, which will be stamping operational performance before broader deployment (should be valid as well for major ground upgrades)

A similar approach as above for avionics should be adopted for an overall air-ground end-to-end system including the ground systems elements. However, any details on such process will need to be subject to the implementing / certification authority.

Action: Ensure the implementation of an overall air-ground system test and certification process is needed for the datalink system. CSPs already have specific processes to accept new avionics on their network and to test new functionality within the system. These existing processes should be evaluated as key processes within an overall, end-to-end air-ground system test and certification programme. Performance criteria as well as associated tests have to be clearly defined and agreed to for all datalink ground sub-systems.

The development of the process and of the reference material will be overseen by the air/ground datalink implementing function, and the validation of adherence will be performed by the certification and oversight function.

Gain: Clear acceptance process valid for all sub-systems. More robust and reliable implementations.

Link to: NetworkOversight-01, NetworkOversight-03, Avionics-01

Timeframe: To be initiated as soon as possible, and established by 2020.

Standards-02: Include the selected interoperability improvements and clarifications in the relevant standards, and implement the resulting changes.

Associated findings: Listed by priority in terms of operational impact:

- Non-use of IDRP: the IDRP routing protocol represents a very important part of the X25 traffic (~60% of X25 Data PDU). The proposed optimisation is to offer the possibility to inhibit the use of IDRP in the air/ground link. (cf. D10 OPTIM10 & section 5.12).
- Avionics Handoff analysis: The performed simulations and interoperability tests explain how today, the airborne initiated handover triggering decisions and timing are impacting the system performance, mainly in complex ground coverage. Avionics suppliers also shared and discussed the main principles for handover management in a detailed study. This detailed study has been

conducted by avionics partners in order to analyse the main reasons behind aircraft handovers. In congested areas, or areas where there is a lack of coverage, the number of handovers increases drastically for all avionics configurations. The simulations identify differences between the avionics implementations which lead to various levels of performance in maintaining reliable connectivity. These simulations results highlight that handovers based on SQP value seem to be not appropriate, as the interoperability tests showed that the SQP scale is not aligned between tested VDRs and are not always providing a fair view about the signal quality (cf. D10, Section 6.5.1).

- A potential solution could be to review the airborne handover management, which should not be limited to an avionic only decision. Enhancement and mitigation will come with MF ground deployment (based on traffic volume, management of frequencies and ground initiated handoff). Close coordination between the airborne and the ground will be required.
- Concatenate CPDLC LACK with TP4 ACK: as the use of CPDLC LACK is mandated in Europe, when a TP4 frame is received, an AK-TDPU is sent before the CPDLC LACK. This implies the sending of 2 TPDUs, leading to at least 2 AVLC PDUs. In order to reduce the number of TP4 PDU transmissions, it was recommended to concatenate the CPDLC LACK (DTPDU) and the TP4 ACK in the same CLNP message. (cf. D10 OPTIM8 & section 5.10).
- Uplink T1N1 situation: on the operational network the loss of VDL2 communication was observed due to exhaustions of uplink N2 retries with relation to expirations of T1 re-transmission timer (so-called Uplink T1N2 situations). The operational data were analysed and possible solutions were discussed between partners. Note that the occurrence of the issue related to this topic on operational network is high (cf. OPTIM13 in D10).
- ATN/AOA prioritizing at ground side: long AOA messages negativity impact the performance of the surrounding aircraft. ELSA is of the view that basic QoS mechanisms are needed to avoid the overlapping between AOA and ATN ATC on the temporal resources. The definition of the QoS mechanisms has to be followed-up in the appropriate standardisation group.
- Reduce ground ACARS latency: a downlink AOA message is acknowledged with an AOA General Response. This General Response is generated by the ground network with a given latency. If this delay becomes higher than AVLC T2, a VDL2 acknowledgment (RR) is generated by the AVLC layer before the General Response. But, if this latency stays below T2, the AVLC acknowledgment could be merged with General Response using an AVLC INFO. Note that on the operational network the average ACARS latency is around 800ms. (cf. D10 Optim11).

Through interoperability testing, conducted in two waves, different issues and potential enhancements have been identified. Especially, the avionics' MF interoperability tests have allowed covering main MF use cases as follows:

- FSL (Frequency Support List, air and ground)
- GRAIHO (Ground Requested Air Initiated Handover)
- Auto-tune commands included in LE and HO responses
- Air-ground transition (FSL-based)
- Ground-air transition (FSL-based)

The overall test results of the different avionics configuration ("best in class") showed a good support of the tested baseline for the different VDL2 MF mechanisms. Only some minor issues have been identified (see D10, Section 6).

The issues and enhancements that have been identified can be classified as follows:

- Non-conformity issues due to lack of validation (some of the issue have been fixed in the second iteration and other point are still under analysis by manufacturers)

- Difference of implementations between avionics impacting operational network performance. This difference is sometime explained by existence of grey zones in the standardisation (gaps) that will require standards clarifications.

- Robustness issues detected in stress test environment.

- Enhancements identified and proposed to manufacturers.

Action: The air/ground datalink implementing function shall coordinate the implementation of the identified fixes and optimisations, and where needed, the update of the relevant standards (ICAO Manual on VHF Digital Link (VDL) Mode 2 (Doc 9776). International Civil Aviation Organisation, EUROCAE ED-92B / MOPS for an Airborne VDL Mode2 System operating in the frequency range 118-136,975 MHz). Based on the categorisation of the identified issues and findings, updates will be deployed with potential new ATN B1 builds, for instance for new aircraft types, or next generation ATN B2 data link systems. Relevant test methods shall be included in the end-to-end certification process.

- In particular, priority is to be given to the incremental removal of IDRP usage in air/ground links, due to its expected high benefits.
- Avionics manufacturers to consider MF fixes and the implementation to concatenate CPDLC LACK with TP4 ACK.
- Handover: different options have been discussed, but ELSA has not developed a final proposal. This topic is be continued immediately by the standardisation workgroup.

Gain:

- A significant reduction of X25 frames, especially with the IDRP removal.
- Harmonise the VDL2 handover procedures/management for improved VDL2 link usage.
- Concatenate CPDLC LACK with TP4 ACK will have positive impact on reducing PA rate as well as reducing slightly the ATN payloads.
- Significantly better connection stability possible, because there is a high occurrence for peer loss of communication
- ATN/AOA prioritizing at ground side will allow the secure and seamless segregation of the data paths (ATN & AOA) as so to avoid network congestion
- Some slight improvements were observed while reducing ACARS Latency.

Linked to: Standards-01, NetworkOversight-01

Timeframe: Standardisation, when required, to be started as soon as possible, in order to achieve implementation by 2025. A joint VDL group (AEEC DLK subcommittee, EUROCAE WG-92, RTCA-214 VDL-SG) has already been put together and is ready to work on ELSA outcomes.

Standards-03: Include updates for MF interoperability in the relevant standards.

Associated findings: The MF interoperability tests have highlighted several points and situations that could be clarified in the standards. A list of possible recommendations, enhancements and/or standard clarifications for aircraft implementations is provided here below:

Aircraft should always save FSL provided in XID (air-FSL when airborne, gnd-FSL when on the ground), regardless of the origin ground station status (current or non-current).

Aircraft should ignore frequencies advertised in XID_RSP_LE and XID_RSP_HO that already failed to improve AVLC link reliability by reducing the number of handover attempts and avoid closed-loop

situation. Aircraft should ensure that the first frequency/ground station selection is made at random from the FSL regardless of the operational environment or test conditions, accordingly to AEEC 631 standard. Any entry shall have an equal probability of being selected in order to introduce a "random load balancing" between frequencies and/or ground stations. A selection based on a deterministic algorithm may lead, in the worst case scenario, to all aircraft selecting the same frequency and/or ground station. When rejecting an autotune, aircraft should adapt the LCR cause parameter to clarify why the autotune was rejected, specially accordingly to AEEC 631 chapter 9.8.1. Explicit LCR cause parameters may ease any performance analysis of an operational network. In addition, a standards recommendation for ground implementations is provided: Ground stations that provide FSL in XID should advertise all (frequency/ground station) pairs that are available around the transmitter. This allows the aircraft, once switched to the alternative frequency, to have alternative VGSs to immediately connect to, if it failed to establish connection with first VGS.
Action: The implementing function, manufacturers and CSPs shall include the MF updates in the relevant standards.
Gain: Improvement of overall network stability by ensuring a predictable behaviour.
Linked to: NetworkOversight-01
Timeframe: To be initiated now (2016) in order to implement for 2025.

6.4 ATN/VDL2 Network Implementation and Oversight Framework

NetworkOversight-01: Establish/empower a pan-European air/ground datalink implementing function having appropriate steering responsibilities.
Associated findings: Whatever the number of issues found or recommendations issued for correction during ELSA, this project is just a trigger for solutions during the ATN/VDL2 lifetime. The Data Link constituents (avionics, ground network, services, technologies, users, overall CSP RF coverage…) will evolve over time and new issues may arise. There is a need to have a pan-European function that will be responsible to follow the overall performance reported by the performance monitoring and spectrum coordination function (see NetworkOversight-02), to identify needs for evolutions, to identify issues, to assess the (new) solution(s) and resolution measures and to coordinate and steer their implementation. Continuous coordination between Stakeholders (e.g. CSPs, ANSPs) is needed for an effective design, deployment and operation of Air/Ground Data Link service, to address the technical aspects indicated in the ELSA outcomes (e.g. MF VDL2, VGS optimisation), to address any other future resolutions measures and the implementation of new services/solutions/technologies which will be required to ensure that the performances are met. The involvement of relevant stakeholders is needed - It would allow to follow-up topics with appropriate partners or standardisation bodies in a timely manner. This should include independent expert panels participating to standardisation groups as well as the NM RFF (see NetworkOversight-02).

Action: A properly authorised Implementing Function needs to be established/empowered for air/ground datalink coordination and steering: It would be in charge of maintaining the requirements, of the Network Architecture, of the coordination of the implementation of the deficiency resolutions (e.g. VGSs' deployment and network optimisation process based on ELSA outcomes), it will continuously monitor the network (e.g. addressing channel capacity, loss of performances, Radio Frequency efficiency …) and the achievements of the requirements. It will be responsible for defining the actions based on the current and future findings, referring them to the appropriate authorities, steer and monitor the implementation of resolution measures and of new services/solutions/technologies and report to the regulatory entity. It needs to be ensured via regulation that all actors have to provide the necessary data to the function, for example, relevant avionics equipage information. Some of the tasks that have to be executed by the pan-European air/ground datalink implementing function are: • manage the Air/Ground Data Link Network architecture; • define the future requirements (including Service areas); • define KPIs for this monitoring and update the definitions of the KPIs as new issues are identified, and monitor their achievements with the monitoring coordination function; • steer and coordinate the implementation of the ELSA recommendations; • steer and coordinate the implementation of new services, solutions and technologies to sustain current and future requirements in a cost effective way.
Gain: More effective coordinated analysis, evolution and problem resolution leading to efficient and safe Air/Ground Data Link operations.
Link to: NetworkOversight-02, Standards-03
Timeframe: Addressed as soon as possible and implemented before 2020.

NetworkOversight-02: Establish/empower a pan-European ATN/VDL2 performance monitoring and spectrum coordination function.
Associated Findings: ELSA activities have highlighted issues associated to the ground networks (e.g. DM sent simultaneously to multiple aircraft). Analyses have been able to link those items with a worsening of network performance indicators like the number of uplink N2 or the number of HO on a specific network. The idea is therefore not only to solve the problems identified during ELSA (and for which partners have taken appropriate actions) but to take a step back and see how such issues or inappropriate behaviours could be detected. There is a need to have an independent function that will be responsible to follow and monitor the overall performance (with a set of KPIs related to RF possibly inspired by the ones from ELSA, see Section 3.3.1). One example of a KPI to be monitored and important for identification of RF channel saturation, is a channel utilisation parameter (CU) which is defined in a common way, not individually. It shall be noted that the RF monitoring processes is coordinated by the Radio Frequency Function Group (RAFT, CF. NM-IR) that is reporting to the NM governance (i.e. NMB and SSC). The last RAFT meeting (April 2016) approved the monitoring campaign to measure the performances of the RF

network.

The monitoring of KPIs is dependent on data input. Regulation is needed to secure the provisioning of data from all involved stakeholders, to limit the use of such data, and to define the KPIs to be reported. It should be based on aggregated data to avoid passing of sensible information.

As recommended by ICAO (Annex 10 – ATT I-4 § 4.5.2) a frequency coordination among States is required in the allocation of VDL2 frequencies. This task is allocated to the Network Manager (NM) Radio Frequency Function (RFF) in Commission Regulation (EU) No 677/2011. Details of the function are described in Annex II.

CSPs monitor and manage assigned RF spectrum as necessary to meet customer performance requirements. To improve the current situation, additional coordination is needed between the CSPs, ANSPs, Implementing Function and NM-RFF on RF spectrum use and plans, as identified in Ground-01.

Action:

- Establish/empower a pan-European function to
    - ensure the RF needs and spectrum usage aspects are regularly assessed and coordinated with the stakeholders and the NM-RFF in accordance with the ICAO standard (cf. DOC011), by supporting the coordination indicated in NetworkOversight-01;
    - ensure continuous RF and performance monitoring (channel capacity, uplink collisions avoidance, co-site interference avoidance …) of the entire system comprising airborne equipment, ground equipment and the operation thereof.
- Ensure via regulation that all actors have to provide the necessary data to the function.

Gain: Improvement of effectiveness of VDL2 RF channel allocation and monitoring.

Linked to: Ground-01.

Timeframe: Addressed as soon as possible and implemented before 2020.

NetworkOversight-03: Establish/empower a pan-European ATN/VDL2 end-to end certification and oversight function for validating (ground and airborne) sub-systems' acceptability.

Associated findings: One of the major lessons learnt from ELSA analyses is that implementations of the standard as well as interfaces between sub-systems are essential for overall system performance. There is a need to guarantee that any subsystem deployment or introduction will not degrade the overall VDL2 performance. The analyses of log files and the interoperability tests performed however clearly indicate performance gaps caused by individual system constituents. Even if procedures exist for individual system constituents, it is needed to have a common and balanced approach towards all system constituents. Primary aspect of this is system acceptance, especially at the radio level. Therefore certification needs to be reinforced.

A continuous oversight is also required, ensuring that existing validation procedures and means are coordinated, complemented with additional means where needed, and reviewed for effectiveness

The function will implement the process recommended as Standards-01.

Action: Establish/empower a pan-European ATN/VDL2 end-to end certification and oversight function for validating (ground and airborne) sub-systems' acceptability– in accordance with existing regulatory means. The reinforcement of the independence and completeness of tests and validation, mainly for the new releases/upgrades and their potential impacts on the overall system performances shall be demonstrated. Ensure the application of the validation process recommended for implementation in Standards-01.
Gain: Improved maturity of deployed products.
Link to: Standards-01
Timeframe: Addressed as soon as possible and implemented before 2020.

7 Summary and Outlook

The improvements already achieved from initial deployments (ground and air) of alternate frequencies support the recommendations made by ELSA. The recommendations proposed for implementation will lead, if addressed in a coordinated way by all stakeholders, to an ATN/VDL2 system that provides acceptable performance to support the full deployment of ATN B1 CPDLC service in the European airspace. As an example, best in class avionics have demonstrated that they can provide less than 4 PAs per 100h CPDLC usage (compared to an average rate of 20 PAs per 100h of CPDLC as measured during ELSA project), independently of any other optimisations being implemented on the overall system. It is equally important that channel load is reduced and maintained below the saturation limit (for all flown flight levels) by means of deploying alternate frequencies. This should be monitored with indicators such as uplink retransmission rate that is the expression of collision rate and therefore, channel congestion.

The recommendations proposed for implementation will provide, if addressed in a coordinated way by all stakeholders, sufficient ATN/VDL2 capacity to support the deployment of ATS data link services in the European airspace until future generation network and communication means are available (e.g. ATN/IPS, AeroMACS, Future SATCOM and/or LDACS).The steps to be taken to achieve this improvement support the proposed transition roadmap towards the target technical solution which is based on five VDL2 frequencies. It has been developed with a detailed trade-off analysis and covers VGS deployment, channel allocation, and network management aspects.

Because ELSA focused on technical aspects of ATN/VDL2 deployment, regulatory/organisational, commercial, and legal aspects have not been discussed. The target technical solution is however considered to be compatible with the vision of establishing a European Air Ground Data Communication System (EAGDCS). The proposal for a council decision, COM(2016) 226, related to a decision on a (potential) EAGDCS provides that it is supposed to take into account the outcomes of ELSA and the preceding capacity study, and also the preparatory work for future certification and oversight conducted by EASA for such a system.

It is however important to note that a coordination platform for the current CSPs needs to be established as soon as possible, not only for the CSC. This platform would need participation from ANSPs, manufacturers and the Network Manager, and interfacing to EASA. Several ELSA participants are interested in continuing their collaboration, also for

- continuing to collect and analyse data to demonstrate incremental progress of performance, but also to detect and address unexpected system behaviour, until a monitoring and steering function has been implemented;
- Preparing very large scale demonstrations in two phases
    - 1st phase: MF systems including collected and analysed data to demonstrate incremental progress of performance, but also to detect and address unexpected system behaviour;
    - 2nd phase: potential addition of new complementary communications means (e.g. ATN/OSI over SATCOM and AeroMACS).

Complementary validation activities:

- Conducting end-to-end (air and ground) system interoperability tests on test benches simulating specific scenarios, including MF;
- Further studying a cellular-like MF network approach;
- Revising and refining the capacity study results based on ELSA inputs.

A Frequency Use Models related to MF Operation

The deployment of VDL2 multi-frequency in Europe takes place in a context where different VHF infrastructure provision models already co-exist.

The initial situation for the provision of Air/Ground communication services was based on the existence of two data link service providers (DSP), namely SITA and ARINC. Each DSP owns and operates its own network of VHF stations, serves its own airline customers and advertises exclusively its own service on the infrastructure that it operates.

The current situation is more nuanced. A number of ANSPs have indeed decided to deploy and operate their own network of VHF stations. These ANSPs become, *de facto*, their own DSP. They may enter different types of agreements with SITA and ARINC to determine which service is being advertised to airlines on their VHF network.

A number of concepts need to be explained:

1. DSP ID: when an aircraft wants to establish a VDL2 link, it has to capture a VHF station operated by the DSP with which the aircraft operator has a contract or a preference. To that end, a VHF ground station will emit, on a regular basis, a message on the VDL2 CSC frequency identifying which CSP operates the station. This message is called a <u>Ground Station Information Frame</u> (GSIF) and it contains identification (ID) of the CSP in question. In the current situation only two DSP IDs exists: SITA and ARINC. Indeed, the VDL2 standards have only defined these two DSP IDs, and avionics are developed to only look for one of these two DSP IDs. A third DSP ID would require a change in avionics.
2. An ANSP that owns and operates its own network of VHF stations has to be considered as its own DSP. However, this DSP can only advertise the DSP IDs from SITA and ARINC, for the reason mentioned under point 1.
3. VDL2 frequency licenses can only be granted by national authorities. The DSP, whether SITA, ARINC or an ANSP, has to request and obtain the proper VDL2 frequency license(s) in order to operate the frequency(-ies) in question. The DSP will therefore become the frequency licensee once such a license has been granted by a national authority for operation in the associated country. The area for which a frequency license has been granted can be associated with a Service area.
4. In the aeronautical spectrum, national authorities are expected to grant frequency licenses in accordance with the frequency plan defined by the FMG. The VDL2 CSC channel being a channel used by everyone, DSPs and aircraft, every DSP operating in a given Service area should become a CSC frequency licensee for that area. The VHF stations composing the SITA infrastructure only emit the SITA ID, and likely the VHF stations composing the ARINC infrastructure only emit the ARINC ID. In this case, the SITA VHF network and the ARINC VHF network form each a <u>Single DSP ID System</u>.
5. ANSPs that are their own DSPs have to decide whether they will advertise only one DSP ID, or both DSP IDs on their VHF network. To that end, they need to enter into adequate agreements with SITA and/or ARINC. If they partner with only SITA, or only ARINC, the ANSP will emit only its partner's DSP ID, and its VHF network forms also a Single DSP ID System. If however the ANSP partners with <u>both</u> SITA and ARINC, it will emit both DSP IDs, and its VHF network forms a <u>Dual DSP ID System.</u>
6. The CSC channel, as stated earlier, must be used by everyone. Aircraft connecting to the CSC channel will hear the DSP IDs of both SITA and ARINC on that CSC channel. For that reason, the CSC channel is described as a <u>Two-GSIF Channel</u>. The GSIF, containing either the SITA DSP ID or the ARINC DSP ID, is emitted according to the following cases:
   a. In Service areas where both SITA and ARINC operate their own network, each such network is a Single DSP ID system, and emits only the DSP ID of its operator.

   b. In Service areas where the ANSP is its own DSP, and this ANSP partners with only one of ARINC or SITA (for ease of discussion, let us say SITA) then this DSP operates also as a Single DSP ID system emitting only the SITA DSP ID. In this example, the ARINC DSP ID is emitted by the ARINC VHF network in this Service area.
   c. In Service areas where the ANSP is its own DSP, and this ANSP partners with both ARINC and SITA, then this DSP operates as a Dual DSP ID system emitting both the ARINC and the SITA DSP IDs.
7. The introduction of VDL2 multi-frequency requires additional VDL2 frequencies, in addition to the CSC channel. From a theoretical perspective, every additional VDL2 channel can possibly be used in any of the following modes:
   a. Either both the SITA and the ARINC GSP IDs will be emitted on that additional frequency, and its frequency, just as the CSC, is a Two-GSIF Channel;
   b. Either only one DSP-ID is emitted on that frequency, in that case the additional frequency is called a One-GSIF Channel.
8. It is now needed to merge these concepts into global definitions of how, in the multi-frequency analysis conducted in this document, the VDL2 frequencies can be used.
   a. Common Frequency: The CSC, as stated earlier, is common to everyone because it is used by everyone, regardless of which DSP operates the network of VHF stations, how the DSP ID is being emitted, and who are the frequency licensees. If there are several DSPs active in a given area, the ground stations, operating in the CSC Frequency, belong to the separate RF networks operated by these DSPs. Each such DSP is a CSC Frequency Licensee in the area in question. Generalizing this case, the term Common Frequency means that *"ground stations operating on a common VDL Frequency in a Service area are managed by more than one Frequency Licensee with separate RF networks"*
   b. Reserved Frequency: If there is only one DSP in a given area, this DSP will be the sole frequency licensee for the area in question, and all the VHF stations will belong to the RF network operated by that DSP. This is captured by the term reserved frequency meaning that "*all ground stations operating on that VDL frequency in a specific area are under the responsibility of one unique Frequency Licensee who is responsible of managing the traffic on that RF network*"
9. These two definitions can be mapped with the current situation in Europe, as shown in the following table:

Table 12 Currently Frequency Use Model - Example

Service area	DSPs	DSP ID	DSP ID System	CSC Channel	Common Frequency	Reserved Frequency
Germany	DFS	SITA	Single	Two-GSIF Channel	CSC	None
	ARINC	ARINC	Single			
United Kingdom	SITA	SITA	Single	Two-GSIF Channel	CSC	None
	ARI NC	ARINC	Single			
Italy	ENAV	SITA	Dual	Two-GSIF Channel	None	CSC
		ARINC				

10. These concepts apply also to how additional VDL2 frequencies could be used in theory. Let us, for the sake of understanding these concepts, assume the following two examples (these are hypothetical examples that serve only the purpose of explaining the concept):
    Example 1
    a. The first additional VDL2 (let us call it F2) will be allocated for use in the airport terminal area, and everyone will use it;
    b. The second additional VDL2 (let us call it F3) will be allocated for use in the en-route area, and devoted to the SITA DSP ID in the whole of Europe;

c. The third additional VDL2 (let us call it F4) will be allocated for use in the en-route area, and devoted to the ARINC DSP ID in the whole of Europe;

The following tables can be drawn:

Table 13 Future Frequency Use Model – Example 1

Frequency F2					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F2 Channel**	
Service area 1	ANSP1	SITA	Single	Two-GSIF Channel	Common Frequency
	ARINC	ARINC	Single		
Service area 2	SITA	SITA	Single	Two-GSIF Channel	Common Frequency
	ARINC	ARINC	Single		
Service area 3	ANSP2	SITA	Dual	Two-GSIF Channel	Reserved Frequency (to ANSP2)
		ARINC	Dual		
Frequency F3					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F3 Channel**	
Service area 1	ANSP1	SITA	Single	One-GSIF Channel	Reserved Frequency (to ANSP1)
	ARINC	Not operating	Not operating		
Service area 2	SITA	SITA	Single	One-GSIF Channel	Reserved Frequency (to SITA)
	ARINC	Not operating	Not operating		
Service area 3	ANSP2	SITA	Dual	One-GSIF Channel	Reserved Frequency (to ANSP2)
Frequency F4					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F4 Channel**	
Service area 1	ANSP1	Not operating	Not operating	One-GSIF Channel	Reserved Frequency (to ARINC)
	ARINC	ARINC	Single		
Service area 2	SITA	Not operating	Not operating	One-GSIF Channel	Reserved Frequency (to ARINC)
	ARINC	ARINC	Single		
Service area 3	ANSP2	ARINC	Dual	One-GSIF Channel	Reserved Frequency (to ANSP2)

Example 2

a. The first additional VDL2 (let us call it F2) will be allocated for use in the airport terminal area, and:
   - will be used by everyone in the Service areas managed by means of Single DSP ID systems
   - will be used with no constraints on GSIF in the Service areas managed by means of Dual DSP ID systems;

b. The second additional VDL2 (let us call it F3) will be allocated for use in the en-route area, and:
   - devoted to the SITA DSP ID in the Service areas managed by means of Single DSP ID systems
   - with no constraints on GSIF in the Service areas managed by means of Dual DSP ID systems;

c. The third additional VDL2 (let us call it F4) will be allocated for use in the en-route area, and:
   - devoted to the ARINC DSP ID in the Service areas managed by means of Single DSP ID systems
   - with no constraints on GSIF in the Service areas managed by means of Dual DSP ID systems;

The following tables can be drawn:

Table 14Frequency Use Model – Example 2

Frequency F2					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F2 Channel**	
Service area 1	ANSP1	SITA	Single	Two-GSIF Channel	Common Frequency
	ARINC	ARINC	Single		
Service area 2	SITA	SITA	Single	Two-GSIF Channel	Common Frequency
	ARINC	ARINC	Single		
Service area 3	ANSP2	SITA	Dual	Two-GSIF Channel	Reserved Frequency (to ANSP2)
		ARINC	Dual		
Frequency F3					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F3 Channel**	
Service area 1	ANSP1	SITA	Single	One-GSIF Channel	Reserved Frequency (to ANSP1)
	ARINC	Not operating	Not operating		
Service area 2	SITA	SITA	Single	One-GSIF Channel	Reserved Frequency (to SITA)
	ARINC	Not operating	Not operating		
Service area 3	ANSP2	SITA	Dual	Two-GSIF Channel	Reserved Frequency (to ANSP2)
		ARINC	Dual		
Frequency F4					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F4 Channel**	
Service area 1	ANSP1	Not operating	Not operating	One-GSIF Channel	Reserved Frequency (to ANSP 1)
	ARINC	ARINC	Single		
Service area 2	SITA	Not operating	Not operating	One-GSIF Channel	Reserved Frequency (to ARINC)
	ARINC	ARINC	Single		
Service area 3	ANSP2	SITA	Dual	Two-GSIF Channel	Reserved Frequency (to ANSP2)
		ARINC	Dual		

Example 3: (Long Term)

As detailed in D09 Section 4.3.2, the recommended Target Long term Solution for EU VDL MF network evolution is one RF Network in each Service area, operating reserved frequencies with Two-GSIF channels. It is assumed that 4 additional VDL2 frequencies will be allocated for use in Europe.

a. The first additional VDL2 (let us call it F2) will be allocated for use in the airport terminal area, with no constraints on GSIF: each Service area is managed by one DSP by means of a Dual DSP ID system;

b. The second additional VDL2 (let us call it F3) will be allocated for use in the en-route area, with no constraints on GSIF: each Service area is managed by one DSP by means of a Dual DSP ID system;
c. The third additional VDL2 (let us call it F4) will be allocated for use in the en-route area, with no constraints on GSIF: each Service area is managed by one DSP by means of a Dual DSP ID system;
d. The fourth additional VDL2 (let us call it F5) will be allocated for use in the airport terminal area, with no constraints on GSIF: each Service area is managed by one DSP by means of a Dual DSP ID system.

The following tables can be drawn:

Table 15 Frequency Use Model - Example 3

Frequency F2 (implemented in Airport)					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F2 Channel**	
Service area 1	DSP1	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 2	DSP2	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 3	DSP3	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Frequency F3 (implemented en-route)					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F3 Channel**	
Service area 1	DSP1	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 2	DSP2	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 3	DSP3	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Frequency F4 (implemented en-Route)					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F4 Channel**	
Service area 1	DSP1	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 2	DSP2	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 3	DSP3	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Frequency F5 (implemented in Airport)					
Service area	**DSPs**	**DSP ID**	**DSP ID System**	**F4 Channel**	
Service area 1	DSP1	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 2	DSP2	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency
Service area 3	DSP3	SITA ARINC	Dual	Two-GSIF Channel	Reserved Frequency

NOTE: the number of Service areas will depend on how they will be defined in the future (e.g. they could be identified with FABs, or they could be new "entities" established regardless of State boundaries)

B Service Areas

Europe has been characterised by an extended and consolidated heterogeneity in operational and technical needs: there are areas with high demand of air traffic to manage and other areas which require less active efforts. There are also areas with technical coverage requirements very different from others. Therefore, a single and equal proposal for a VDL2 deployment for all Europe would be not appropriate to cover the deep distinctions existing among the various European Aviation players.

ELSA has acknowledged these discrepancies and has decided, for the MF deployment actions identified during the activities performed in the ELSA project, to adopt the concept of Service area developed in the A6 Study on Data Link Services.

Service areas are portions of airspace, homogeneous in terms of operational and technical needs to provide data-link services in a safe, secure and efficient way. They could be identical with FABs or as new entities established regardless of state boundaries.

The “idea” to embrace this concept is in line with the principles founding the Single European Sky: reduce the heterogeneity of existing European ATM environment, ensuring the provision of services in a more harmonised and integrated way (for example introducing the FABs).

A Service area is established to improve a pre-existing condition into a one more responsive to the technical and operational needs of the CSPs and ANSPs operating in that Area. The purpose is to maximise experience, knowledge, competence and work and render the provision of the data-link services more safe and efficient. The reorganisation aims also at a better use of the existing possibilities, minimizing the economic impact of a change.

The identification of the Service areas will be a specific task of the Implementing Function that ELSA has identified as the main “operational entity”, capable to detect and characterise all the technical and operational aspects affecting a specific region.

The Service areas will be based on a performance-based approach, where the objectives, levels of service and indicators are well established.

C ELSA Interoperability Test Details

The objective of the ELSA interoperability tests activities was to stress avionics and to assess their multi-frequency operations in a representative European Airspace using representative testing platform[11].

The aim of the testing platform was to reproduce a fully representative RF environment to the tested avionics (i.e. Systems under test or SUTs), in order to analyse and measure its performances and its ability to maintain the end to end CPDLC connection with the ground network in a loaded traffic environment (i.e. like in core Europe end of 2015).

The testing platform was providing, in real-time, the SUT with the simulated aircraft GPS position (i.e. using the appropriate interface, here the A429 bus) according to a defined flight-plan. The testing platform was connected to the SUT VDR using the appropriate RF cables and attenuators. The Testing platform was also providing the computed RF signal that the SUT should experience at each position using adaptive radio transceivers. The RF signal level was computed according to a RF propagation model[12].

The RF propagation model realistically simulates RF physical behaviours, and finely imitates phenomena that may be experienced at aircraft antenna level:

- Free-space /multipath propagation, large scale fading (two ray model)
- Channel sensing per emulated entity (CSMA, TDMA)
- Antenna gain, signal strength levels, noise estimation, Signal-to-Noise Ratio (SNR)
- Bit Error Rate (BER), Frame Error Rate (FER), Reed-Solomon correction effects

While doing the virtual flight inside the simulation the SUT was CPDLC connected to the ground network and was doing VDL2 handovers between seen ground stations according to the variation of the uplink SQPs.

In addition to the SUT virtual flight, all VDL2 traffic (i.e. Aircraft & ground network) of the European airspace area was simulated inside the testing platform environment. In the scope of ESLA, this traffic was extracted from the typical days in 2015 (December and April), in addition to the forecasted traffic for the periods 2018 and 2025.

This traffic was generated by the emulated flights surrounding the SUT and by the emulated ground network (cf. D10 Annex B, C, D, M and N). Flight information were extracted from the typical days VDL2 logs. E.g. a peak of 1,170 simultaneously active aircraft over Europe is reached. These simulation activities required approximately 230 hours of cumulated executions, corresponding to 116,000 hours of virtual flights and nearly 33 million exchanged messages.

[11] Made of computing servers and radio transceivers, connected to the avionics bench using VHF and A429 interfaces

[12] Used as the model of reference for all European and U.S. VHF data link capacity studies since 2004.

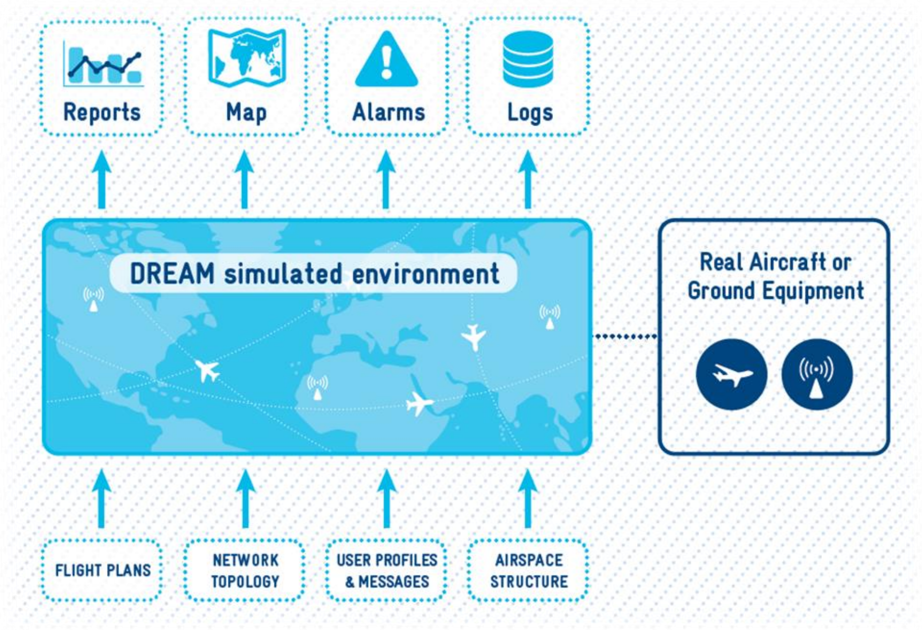


Figure 41 ALTYS DREAM Testing Platform, functional diagram (from D10)

The interoperability tests activity performed between representative avionics benches and the test platform allowed to test a wide scope of functions on the avionics side – starting from the lowest physical layer with the VDR RF tests, the VDL2 MF tests in a representative environment and scenarios, virtual flight tests and ending by end-to-end CPDLC tests.

In addition to the typical flight some extra unitary tests were exercised. These tests allowed to verify aircraft behaviour in situations not always experienced during the simulation (or to reproduce the detected issues).

Note that the unitary tests and the simulation environment were done using the last standard release[13] as the targeted baseline to validate. The avionics were supposed to be compliant with this baseline.

These unitary tests (cf. D10 Annex I to K) were covering the different protocol levels as follows:

- VDL2 level
    - VDL2 physical layer tests (VDR RF tests) in order to assess the VDR decoding and capture performance in loaded environment (e.g. High CU, High traffic load) and in abnormal situations (e.g. collided PDUs, truncated PDUs). Check the VDR implementation for the different correction algorithms (e.g. Header FEC, Reed Solomon). Check the performance of the burst detection algorithm. Check the VDR sensitivity and SQP scale implementation. Compare the VDR performance for the different VDL2 frequencies. Check the multi-frames decoding and the bit-stuffing implementations. Check the impact of the D08PSK constellation offset.
    - VDL2 Link and Handover management tests in order to assess the handover performance and behaviour.
    - VDL2 disconnect management (e.g. DISC, DM, N2)
    - VDL2 MF tests based on the “EUROCONTROL VDL2-MF test cases” document[14] covering all the VDL2 MF methodologies - FSL (Frequency Support List, air and ground), GRAIHO

[13] RTCA DO-178B or C whenever applicable, ED-12B, European Commission regulation and the applicable protocol standards (ARINC 631 and 750, EUROCAE ED92ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

[14] Draft document circulated by Eurocontrol

(Ground Requested Air Initiated Handover), Auto-tune commands included in LE and HO responses, Air-ground transition (FSL-based), Ground-air transition (FSL-based)
   - Verify the VDL frequency scan behaviour and its impact on the end to end performance
- ATN Stack
   - X25 handover between CSPSs
   - ATN disconnect management (e.g. X25 Clear Request, IDRP loss, ESIS management)
- Application level
   - CM/PM-CPDLC communication with ATC centre
   - Provider Abort scenarios
   - Long delays scenarios
- Protocols timer's, counter's & finite state machine's implementation compliance and behaviours analysis
- **The list of interoperability tests (including MF) performed within ELSA were:**

Table 16 List of ELSA interoperability tests.

Test Reference	Purpose	Covered Standards
AVP_CPDLC_NOCOMM	Identify if the SUT is able to re-establish a CPDLC connection after the previous connection was stopped.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_Delayed_uplinks	Check SUT CPDLC robustness - message latency	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_03	Check SUT CPDLC robustness - CPDLC V2 support	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_04	Check SUT CPDLC robustness - CPDLC V2 support	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_SC214	Check SUT CPDLC robustness - CPDLC V2 support	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_Simult_Dialogues	Check SUT CPDLC robustness - Simult. Dialogues with same type	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_NO_CM	Check SUT TP4 robustness - No CM	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_high_CU	To check that the SUT is able to maintain a CPDLC connection in a high-CU environment	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_IDRP_CM_logon	To check if the Airborne System is able to send a CM-logon without IDRP.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_IDRP_loss	To check that the Airborne System is able to manage IDRP connection loss.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_TP4_01	Check SUT TP4 robustness - Unknown address	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_CNF	Retrieve SUT values : N2 T1min T1max T1exp T3min T3max T3exp (impact on the results of LE/HO tests)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

AVP_VDL2_TG1	Start the SUT with no VGS available. How many time does the SUT listen on 1 frequency before switching to alt. Freq ?	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_ATN_Router_list	ATN router number limit	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_ ATN_Router_choice	Router choice	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_T1_T3_low_CU	Get T1 and T3 timers when CU is low (approx. 6%)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_T1_T3_high_CU	Get T1 and T3 timers when CU is high (approx. 80%)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_TG2	Get TG2 value for a station the SUT is not connected to.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_HO_TG2	Delay between last received PDU from GS#1 and attempt to switch to GS#2	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_LE_TG2	Delay between last received PDU from GS#1 and attempt to switch to GS#2	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_station_switches	VDL2 station switches	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_TG5	Determine TG5	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_preference	Behaviour against a X25 service supported (or not)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_mngt	VDL2 X25 availability mngt	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_update	VDL2 X25 availability update	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GRAIHO_Frequencies	GRAIHO support	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GRAIHO_mngt	GRAIHO support on same frequency	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GIHO	GIHO support	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GIHO_ERR	Behavior against GIHO from another DSP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_LCR	Check is SUT supports LCR in response to LE-CMD or HO-CMD	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_Services_preference	Check how the SUT manages GSIF with different available services (ACARS-only vs. ATN-only)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_HO_SQP	SQP threshold before switch	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_PECT_Limit	PECT size threshold	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

AVP_VDL2_corrupted_frames	Corrupted AVLC frames management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_corrupted_GSIF	Corrupted GSIF management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_01	Delay between GSIF reception and LE_REQ transmission	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_02	Delay between XID reception and LE_REQ transmission	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_03	Behavior while receiving 2 GSIF from the preferred and the alternative DSP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_04	Behavior while receiving 4 GSIF from the preferred DSP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_01	Test SUT "Back off timer" management (in DATA transfer state)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_02	Test SUT timer "T21" management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_03	Test classic reconnection scenario (ground clearing then accepting reconnection attempts)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_SILENT_DISC	VDL2 Silent DISC	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_HO_SYSTEM_MASK_01	HO is done when the masked DLS addresses are identical (even if one starts with 1 and the other with 0).	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_HO_SYSTEM_MASK_02	LE is done when the masked DLS addresses are NOT identical (even if both start with 2).	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_SNDCF_MI_01	To check that the Airborne System is able to handle a response (CALL-CONFIRM) with M/I bit set to 0 when its request (CALL-REQUEST) contains a M/I bit set to 1.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_SNDCF_MI_01	To check that the Airborne System is able to handle a response (CALL-CONFIRM) with M/I bit set to 1 when its request (CALL-REQUEST) contains a M/I bit set to 0.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Attenuation	Evaluate receiver performance by generating VDL2 bursts with incremental software attenuation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Attenuation	Evaluate receiver performance by generating VDL2 bursts with incremental software attenuation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_INVALID_CRC_11	Check VDL2 checksum implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_INVALID_CRC_12	Check VDL2 checksum implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Bit_Stuffing_21	Check bit stuffing implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Bit_Stuffing_22	Check bit stuffing implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

AVP_BAD_LEN_31	TL1…TL17 implementation Length too short vs. real length sent over the channel	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_BAD_LEN_32	TL1…TL17 implementation Length too short (e.g. DATA having a length of 8 bytes)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_BAD_LEN_33	TL1…TL17 implementation Send 2 separated frames with a short delay, where the first one indicates a length too long and verify if the AC is able to detect the second frame	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_BAD_LEN_34	TL1…TL17 implementation Send data with Length null having DATA followed by correct data just after	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_BAD_LEN_41	TL1…TL17 implementation Change 2 bits the receiver should be able to detect but not to correct with a ratio of 25%	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_BAD_LEN_42	TL1…TL17 implementation Change 1 bit, the receiver should be able to correct with a ratio of 100%	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_D08PSK_OFFSET_5	Phase offset	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_REED_SOLOMON_6	Validate the RS (255,249) correction capability, this code is capable of correcting up to three octets for data blocks of 249 octets.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_REED_SOLOMON_7	Invalid RS where the receiver is not able to correct	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Endurance_Test_8	10000 messages with the highest transmission rate	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Concatenate_RF_SIGNAL_9	Decrease time space between two messages	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_Multi_Frame_10	Generate incremental size of multi-frame	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_SNR_131	Incremental SNR level	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_SNR_132	Incremental SNR level, fixed attenuation of 10 dB	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_TG2_LE	Check TG2 Value and verify VDL2 LE 2 VGS are available: 1 SITA GS1, 1 ARINC GS2	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_ ATN_Router_list	XID with a 25-entry "ATN Router list"	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_SILENT_DISC	Check DM uplink management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_01	Check VDL2 Link Establishment mean time	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_02	Check VDL2 Link Establishment mean time	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_START_3	Check VDL2 Link Establishment management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

AVP_VDL2_START_4	Check VDL2 Link Establishment management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_T1_T3_low_CU	Check Airborne System "Retransmission timer" (T1) and "Link initialisation timer" (T3) calculation (low CU).	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_T1_T3_high_CU	Check Airborne System "Retransmission timer" (T1) and "Link initialisation timer" (T3) calculation (high CU).	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_TG1	Check TG1 implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_TG2	Check TG2 implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_LCR	LCR Management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_Corrupted_AVLC_frames	Corrupted frames rejected with FRMR	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_PECT_Limit	Check PECT table limit	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_01	ISO8208 reconnection mean time	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_02	Check ISO8208 "T21" timer (200 s)	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_X25_03	Classic ISO8208 reconnection	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
SNDCF_MI_01	Ground answer M/I=0 for a downlink M/I=1	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
SNDCF_MI_02	Ground answer M/I=1 for a downlink M/I=0	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_update	Update GSIF and set ATN Router NETs to null	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_preference	ATN preferred if available	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_X25_availability_mngt	ATN preferred if available	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_Services_preference	ATN only vs. AOA only	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_ACARS_General_Response_Disable	ATN Maintained if AOA failed	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_IDRP_loss	Check IDRP loss management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_no_IDRP	Check ATN connection without IDRP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GRAIHO	Check GRAIHO implementation	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

AVP_VDL2_GRAIHO_mgmt	Check GRAIHO management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_Corrupted_GSIF	Validate GSIF parameters values check	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_TP4_50conn	Check TP4 connection management	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_Delayed_uplinks	Delayed CPDLC uplinks	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_DM62	Generate DM62	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GIHO_ERR	GIHO from alt. DSP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_GIHO	GIHO from pref. DSP	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_FSL	GSIF with FSL	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_CPDLC_no_CM	Check if CPDLC can start without CM	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_ACARS_disable	ACARS notified as disable by the current station	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
AVP_VDL2_System_Mask	Check how the avionics handles the System Mask when identifying DSP.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_1_1	TP_EUR_12: Verify that following loss of communication on the current frequency while the aircraft is airborne, the aircraft performs the frequency recovery procedure, and selects a frequency/VGS pair from an airborne FSL and performs a Handoff to the VGS on the selected frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_1_2	TP_ADD_XX: Verify that following loss of communication on the current frequency while the aircraft is airborne, and no FSL is available, the aircraft reverts to the CSC and selects a station to which to perform a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_2_1	TP_ADD_XX: Verify that following loss of communication on the CSC while the aircraft is airborne, and only a ground FSL is available, the aircraft does not select a frequency from the ground FSL.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_2_2	TP_EUR_13: Verify that following loss of communication on the current frequency while the aircraft is airborne, and only a ground FSL is available, the aircraft reverts to the CSC and selects a station to which to perform a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_3	TP_ADD_XX: Verify that following loss of communication on the current frequency while the aircraft is airborne, and failure to handoff to a VGS/Freq from the air FSL, the aircraft reverts to the CSC and selects a station to which to perform a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

TC_AFSL_4	TP_EUR_23: Verify that following a transition from ground to air, after performing a Handoff to a VGS on an airborne frequency, and then receiving an uplink DISC frame while TG5 is still running, the aircraft selects another frequency/VGS pair from an airborne FSL, and performs a successful Handoff to the VGS on the selected frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_5	TP_EUR_24: Verify that following a transition from ground to air, after performing a Handoff to a VGS on an airborne frequency, and then receiving an uplink DISC frame while TG5 is still running, if no further frequency/VGS pair is available in an airborne FSL, the aircraft reverts to the CSC performs a successful Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_AFSL_6	TP_EUR_23: Verify that following a transition from ground to air, after performing a Handoff to a VGS on an airborne frequency, and then receiving an uplink DISC frame while TG5 is still running, the aircraft selects another frequency/VGS pair from an airborne FSL, and performs a successful Handoff to the VGS on the selected frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GFSL_1_1	TP_EUR_15: Verify that following start-up while on the ground, the aircraft selects a frequency/VGS pair from the Ground FSL, and performs a successful Link Establishment or Handoff on the ground frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GFSL_2	TP_EUR_17: Verify that on start-up while on the ground, if the aircraft fails to establish a successful link with any entry in the ground FSL, the aircraft reverts to the CSC, performs a successful Link Establishment, and remains on that frequency without any further attempt to transfer to the ground frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GFSL_3_1	TP_EUR_19: Verify that after a transition from the air to the ground, the aircraft selects a frequency/VGS pair from a ground FSL, and performs a successful Handoff on the ground frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GFSL_3_2	TP_EUR_20: Verify that after a transition from the air to the ground, if the aircraft fails to establish a successful link with any frequency/VGS in the ground FSL, the aircraft reverts to the CSC, performs a successful Link Establishment, and remains on that frequency without any further attempt to transfer to the ground frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GFSL_3_3	TP_ADD_XX: Verify that after a transition from the air to the ground, and the aircraft performs a successful Handoff to a ground frequency and VGS from a ground FSL, if the new link on the ground subsequently fails, the aircraft reverts to the CSC, performs a successful Link Establishment, and remains on that frequency without any further attempt to transfer to the ground frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_TFSL_1_1	TP_EUR_18: Verify that after establishing a link on a dedicated ground frequency, upon becoming airborne the aircraft selects a frequency/VGS pair from an airborne FSL, and performs a successful Handoff to the VGS on the selected frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

TC_TFSL_2_1	TP_EUR_21: Verify that following a transition from air to ground, after performing a Handoff to a VGS on a dedicated ground frequency, and then receiving an uplink DISC frame while TG5 is still running, the aircraft selects another frequency/VGS pair from a ground FSL, and performs a successful Handoff to the VGS on the selected frequency.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_TFSL_2_2	TP_ADD_XX: Verify that when the aircraft fails to handoff to a frequency/VGS pair selected from a ground FSL it will select another frequency/VGS pair and perform a successful handoff to the selected VGS.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_TFSL_3	TP_EUR_22: Verify that following a transition from air to ground, after performing a Handoff to a VGS on a dedicated ground frequency, and then receiving an uplink DISC frame while TG5 is still running, if no further frequency/VGS pair is available in a ground FSL, the aircraft reverts to the CSC performs a successful Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_TFSL_4_1	TP_EUR_24: Verify that following a transition from ground to air, after performing a Handoff to a VGS on an airborne frequency, and then receiving an uplink DISC frame while TG5 is still running, if no further frequency/VGS pair is available in an airborne FSL, the aircraft reverts to the CSC performs a successful Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_TFSL_4_2	TP_ADD_XX: Verify that when the aircraft fails to handoff to a frequency/VGS pair selected from an air FSL it will select another frequency/VGS pair and perform a successful handoff to the selected VGS.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_1	TP_EUR_2: Verify correct system behaviour under normal conditions when an Autotune command is included in the XID_RSP_HO following an Air-Initiated Handoff.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_2_1	TP_EUR_7: Verify that when the aircraft receives an Autotune parameter on the CSC, and all subsequent downlink XID_CMD_HO on the Autotuned frequency are lost, the aircraft continues to attempt to send the XID_CMD_HO using normal re-transmission procedures, and eventually reverts to the CSC and performs successful a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_2_2	TP_EUR_14: Verify that following loss of communication on the current frequency while the aircraft is airborne, and no FSL is present, the aircraft reverts to the CSC and selects a station to which to perform a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_3	TP_EUR_8: Verify that when the aircraft receives an Autotune parameter on a non-CSC frequency, and all subsequent downlink XID_CMD_HO on the Autotuned frequency are lost, the aircraft continues to attempt to send the XID_CMD_HO using normal re-transmission procedures, and eventually reverts to the CSC and performs a successful Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

TC_HO_4	TP_EUR_9: Verify that when the aircraft receives an Autotune parameter on the CSC, and all subsequent uplink XID_RSP_HO on the Autotuned frequency are lost, the aircraft continues to attempt to send the XID_CMD_HO using normal re-transmission procedures, and eventually reverts to the CSC and performs successful a Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_5	TP_EUR_5: Verify that in the event of loss of an XID_RSP_HO carrying the Autotune command the existing link is maintained until expiry of TG5 on the ground, and that the aircraft re-attempts the air-initiated handoff in accordance with published procedures.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_HO_6	TP_EUR_10: Verify that when the aircraft receives an Autotune parameter on a non-CSC frequency, and all subsequent XID_RSP_HO on the autotuned freq are lost, the aircraft continues to attempt to send XID_CMD_HO using normal re-transmission procedures, and eventually reverts to the CSC and performs a successful Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_LE_1	TP_EUR_1: Verify correct system behaviour under normal conditions when an Autotune command is included in the XID_RSP_LE following Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_LE_2	TP_ADD_XX: Verify that following receipt of an Autotune included in an XID_RSP_LE, and the subsequent Handoff on the new frequency fails, the aircraft reverts to the CSC and selects a station to perform Link Establishment.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GRAIHO_1	TP_EUR_3: Verify correct system behaviour under normal conditions when an Autotune command is included in an XID_CMD_HO (P=0) forming a Ground Requested Air-Initiated Handoff.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GRAIHO_5	TP_EUR_6: Verify that in the event of loss of the XID_CMD_HO (P=0) carrying the Autotune command the existing link is maintained and that the ground re-attempts the Autotune in accordance with published procedures.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_GRAIHO_6	TP_EUR_4: Verify that following a successful Autotune, upon encountering falling SQP, the aircraft selects an alternative VGS from its PECT on the same frequency, and performs a successful Air-Initiated Handoff.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_CLR_1	TP_ADD_XX: To verify that if the aircraft rejects an Autotune delivered in an XID_RSP_LE with a downlink XID_CMD_LCR (P=0) the existing link is maintained.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_CLR_2	TP_ADD_XX: To verify that if the aircraft rejects an Autotune delivered in an XID_RSP_LE with a downlink XID_CMD_LCR (P=0) the existing link is maintained.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual
TC_CLR_3	TP_ADD_XX: To verify that if the aircraft rejects an Autotune delivered in a GRAIHO with a downlink XID_CMD_LCR (P=0) the existing link is maintained.	ARINC 631 and 750, EUROCAE ED092, ED110B, ED120, ICAO and ATN SARPS, VDL2 Technical Manual

D “Best in class” Avionics identified within ELSA

The “best in class” datalink avionics components identified by ELSA are:

1. “Best in class” data link management units
   - AIRBUS:
     - FANS B+ ATSU CSB8.3.
   - Honeywell:
     - MkII+ CMU upgrade from -501 and -521 to -522,
     - EPIC CMF upgrade to Block 3.xx or later,
     - B787 CMF upgrade to BPV3,
     - B777 CMF upgrade to BPv17A BLE.
   - Rockwell Collins:
     - CMU-900 upgrade to CMU Core software 815-5679-505 (refer to CMU-900 Service Information Letter 15-1).

2. “Best in class” VDR units
   - Honeywell
     - RTA-50D PN 965-1696-0F1,
     - RTA-44D PN 064-50000-2052 or with service bulletin SB23-1570 installed,
     - EPIC avionics fitted with mod D or greater for the VDR element.
   - Rockwell Collins
     - VHF-920: P/N 822-1250-002w/SB16 or 822-1250-020w/SB17,
     - VHF-2100: P/N 822-1287-101/180w/SB7 or 822-1287-121/141,
     - VHF-2200 P/N 822-2763-020 or VHF-2200 P/N 822-2763-050.

Equipage data is only available for aircraft on the white list, because airspace users need to report their data when registering their aircrafts for the white list. Otherwise there is no reporting obligation.

About 40% of all flights are ATN-equipped according to EUROCONTROL, and about 30% of the ATN-equipped aircraft are on the white list.

The White List is composed of a few different configurations, 92.5% of which are using AIRBUS, Honeywell or Rockwell Collins avionics.

32.5% of the aircraft on the white list already have “best in class” versions and the remaining 60%[15] of the AIRBUS, Honeywell or Rockwell Collins avionics-equipped fleet on the White List are affected by the upgrade as follows:

- 29% by the AIRBUS CSB8.3 upgrade,
- 19% by the Honeywell RTA-44D upgrade to solve the reset issue,
- 12% by Honeywell CMU/CMF upgrades,
- 18% by the Rockwell Collins CMU upgrade.

[15] Counting has “1” aircraft that needs both VDR and CMU upgrades.

E Multi-Frequency Transition Roadmap

The following has been taken from D09, Section 4.4.

E.1 Introduction

In this paragraph a transition roadmap from the current DLS implementation status to the identified Technical Target DLS Solution (i.e. the European RF network composed by single RF networks operating in defined Service areas) is reported.

The roadmap is focused on RF DLS network implementation considered as the current main DLS open issue while the ground-ground data distribution and the ATM DLS upgrades have been considered as already available or discussed in other DLS related activities.

Furthermore, it is only relevant to the technical aspects because the other ones, like Regulatory, Institutional and Legal, are out of the scope of the ELSA study and they should be opportunely treated in other dedicated boards.

A stepwise approach to reach the Technical Target Solution has been followed in order to avoid a unique big transition very difficult to implement and the timeline has been set with three milestones defined as short, medium and long term. These milestones have been identified according to the introduction of baselines B1, B2 and B3 as currently planned.

Furthermore, before to start with deployment phase, it should be implemented a CSP/ANSP Coordination Technical Function in order to define all necessary details including:

- to define the Service areas
- to coordinate common to reserved VDL frequency transition plan
- to agree on CSC operations to include RF Loading Thresholds
- to agree on interoperability management (for example, during transition phase, different network architectures, i.e. One-GSIF or Two-GSIF, should be allowed to support VDL multi-frequency operations and ensure seamless transition for avionics between areas implementing different infrastructure types)
- to monitor the RF network capacity levels to anticipate, if necessary, the transition from model B to D.

It shall be noted that the timeline (2025-2030) could be fine-tuned according to the early outcomes provided by the CSP/ANSP Coordination Technical Function.

The following Table 17 summarises the already identified models of RF VDL networks that have been considered in the transition plan:

Table 17 RF VDL networks identified models (from D09)

MODELS	VDL RF operating Networks	VDL RF Frequency Use	GSIF on each Frequency announced by each Network	Existing today	Note
A	MULTIPLE	COMMON	ONE	YES	Current Central EU model
B	MULTIPLE	RESERVED	ONE	NO	**Target Short term evolution for central EU**
C	SINGLE	RESERVED	TWO	YES	Current model deployed in a limited area*
D	SINGLE	RESERVED	TWO	NO	**Target Long term model for EU VDL network evolution**

*Currently deployed by ENAV on Italian airspace.

E.2 The Transition Roadmap

Starting from model A and C, already implemented respectively in core Europe and Italy, and named as D the target solution, the following transition roadmap has been identified (Figure 42):

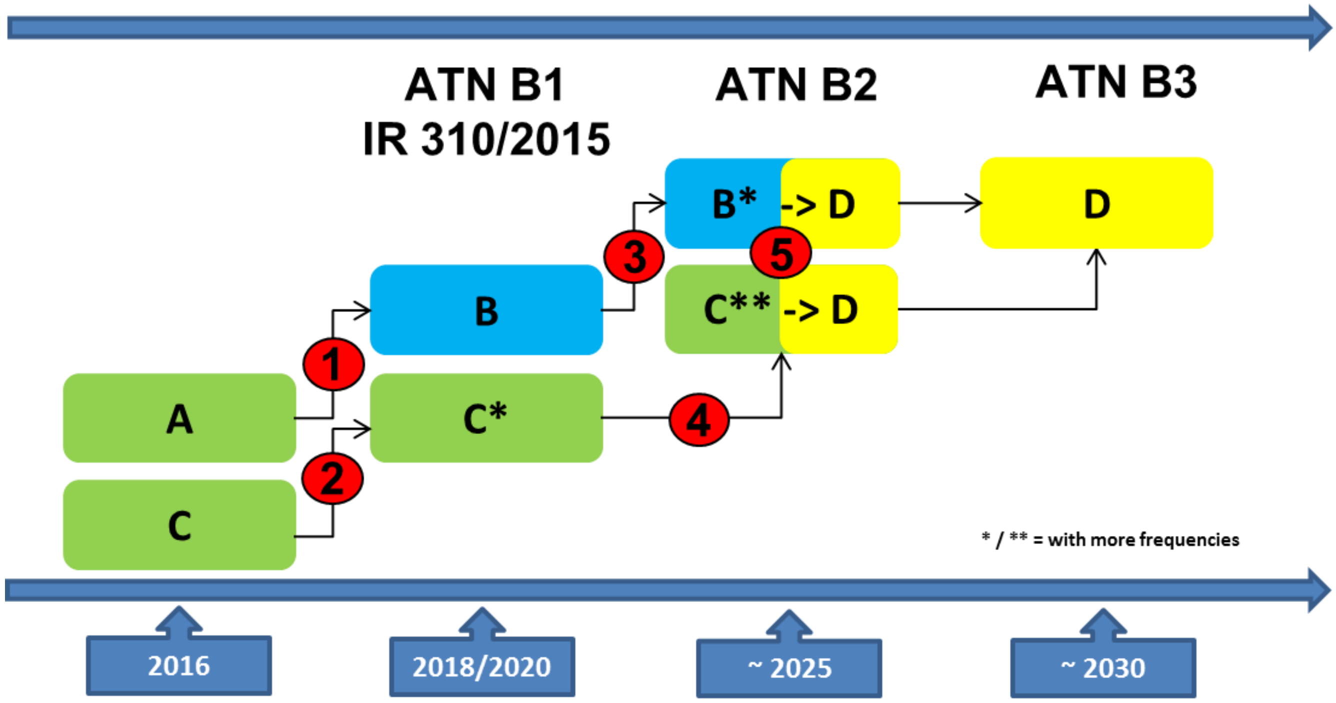


Figure 42 **Transition roadmap** (from D09)

The steps from a model to another one have been identified and the related "requested actions" for moving from a model to another one have been identified and classified.

In order to define the road map timeline, also due capacity considerations have been done starting from the SJU Capacity study.

According to this study the following considerations can be made:

- in core Europe, the current VLD2 system will meet the ATS performances until 2025 with four frequencies in common use with two RF networks using a single squitter technology.
- adding one frequency more (for example, from three to four frequencies) the trend is to gain at least five years for VLD2 life.

So, considering the following improvements introduced by Technical Target solution (Model D):

- adding the fifth frequency
- implementing a single RF network
- using a dual squitter technology (Dual DSP ID system)

It is reasonable to think that more than five years will be gained permitting to the Technical Target Solution to meet the ATS performances until 2030 or more.

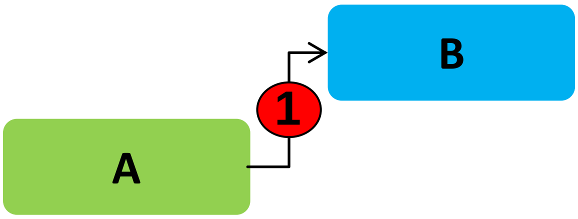
Having said that, hereinafter, there is a short description of the identified steps.

E.2.1 First step: from 2016 to 2018/2020

Transition from model A to B (first phase with an initial frequencies number)

This transition has been considered in order to reduce drastically the interferences and the hidden terminals maximising the capacity and, taking into account the current implementations in core Europe (two RF networks), it is relatively easy to implement. In order to do that, the addition of the fifth frequency is necessary.

- **In any solutions, the addition of the 5th VDL frequency over the current 4 VDL frequency allocation shall be fostered at ICAO FMG Allotment plan level.**



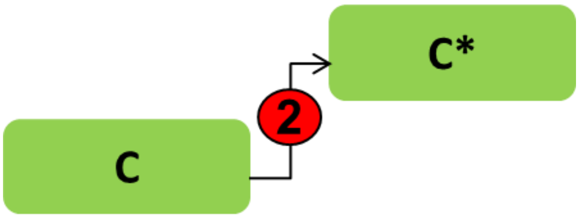
The following actions have to be performed:

- **Action 1:** recommendations to ICAO FMG:
    - transition to 5 VDL frequencies
    - allow dedicated frequency VDL operations on non-CSC channels
- **Action 2:** design and deployment of the new VGS configuration (see Annex G)
    - Many radios are already in place supporting shared frequency operations. These radios, and associated RF support infrastructure, will need to be modified to operate on a new frequency.
- **Action 3:** reconfigure the RF network (see Annex G)
    - The current plan is for SITA to continue operations on 136.875 MHz. ARINC will cease operations on 136.875 and start operations on 136.725 MHz. Most VGS and alternate VDL radios are already in place to support this plan.
- **Action 4:** operational transition.

NOTE: In this phase, implementation of CSP Coordination Function should start also in order, for instance, to coordinate shared to dedicated VDL frequency transition plan and agree on CSC operations to include RF Loading Thresholds.

- **Transition from model C to C***

This transition has been considered only to highlight the implementation of more frequencies (the number of frequencies implemented in each Service areas will be different).



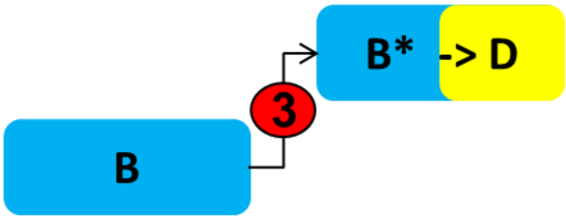
The following actions have to be performed:

- **Action 1:** deployment of new VGS configuration (see Annex G)
- **Action 2:** reconfigure the RF network (see Annex G)
- **Action 3:** operational transition.

E.2.2 Second step: from 2018/2020 to 2025

Transition from model B to B* (completion with all frequencies available)

This transition has been considered only to highlight the implementation of more frequencies (the number of frequencies implemented in each Service areas will be different)



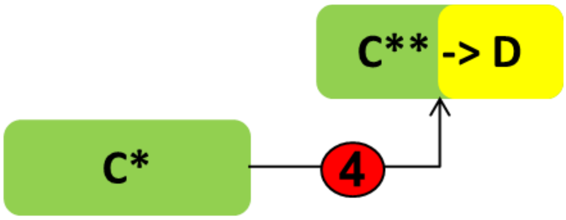
The following actions have to be performed:

- **Action 1:** deployment of new VGS configuration (see Annex G)
- **Action 2:** reconfigure the RF network (see Annex G)

  It is expected that the majority of the effort in the second step will involve increasing the number of VGS supporting alternate VDL frequencies. Some additional VGS may be needed to meet coverage requirements.
- **Action 3:** operational transition.
- **Action 4:** develop plan for transitioning from Model B to D. Plan must consider all Technical, Regulatory, Institutional, Business and Legal issues.

Transition from model C* to C**

This transition has been considered only to highlight the implementation of more frequencies (the number of frequencies implemented in each Service areas will be different)



The following actions have to be performed:

- **Action 1:** deployment of new VGS configuration (see Annex G)
- **Action 2:** reconfigure the RF network (see Annex G)
- **Action 3:** operational transition

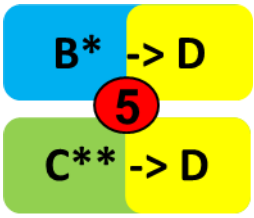
- **Action 4:** develop plan for transitioning from Model C to D. Plan must consider all Technical, Regulatory, Institutional, Business and Legal issues.

E.2.3 Third step: from 2025 to 2030

Transitions from model B* to D and C** to D

The transition from model B* to D has been considered as necessary because, in the current MF framework, due to the scarcity of RF resource, it shall be considered that the entire MF system based on model B will be saturated when the first single GSIF channel comes to saturation. The CSPs have estimated the saturation around 2025 because the SJU Capacity Study cannot be used as reference (it has not studied the "dedicated" frequency configuration). So, in order to mitigate risks, the CSP Coordination Technical Function shall monitor the RF network capacity levels to anticipate, if necessary, the transition from model B to D and also to deploy the identified solution in the most efficient way, exploiting its scalability.

The transition from model C** to D has been considered to highlight the implementation of more frequencies (the number of frequencies implemented in each Service areas will be different) and to address the interoperability issues at the boundaries of the Service area "de facto" existing where Model C is already deployed and the new surrounding Service areas.



For B* to D, the following actions have to be performed:

- **Action 1:** implement B to D transition plan
- **Action 2:** deployment of new VGS configuration (see Annex G)
- **Action 3:** reconfigure the RF network (see Annex F and Annex G)
- **Action 4:** operational transition.

For C** to D, the following actions have to be performed:

- **Action 1:** implement C to D transition plan
- **Action 2:** deployment of new VGS configuration (limited to interfaces)
- **Action 3:** reconfigure the RF network (see Annex F and Annex G)
- **Action 4:** operational transition.

F RF Network Technical Management

This Annex has been adopted from D09, Section 7.3.4. It is part of an internal deliverable within the ELSA study. It investigates the topic of Technical Governance for Multi-Frequency deployment, i.e. it describes the various options by which a VLD2 multi-frequency infrastructure can be deployed and operated, and looked at the pros and cons of each option.

Three options have been identified:

- Service Model: A CSP deploys, owns and operates the VHF infrastructure over a given airspace. It provides the air/ground communication service (VLD2 and ATN routing) against a regular fee to the ANSP. The ANSP should contract more than one CSP, according to the provisions of the Implementing Rule.
- Partnership Model: An ANSP procures the VHF infrastructure from a CSP, owns and operates it, and provides the air/ground communication service (VLD2 and ATN routing) to aircraft. This communication service is advertised to aircraft as the CSP(s) service. The ANSP provides the AOC service as well on behalf of the CSP(s).
- Development Model: an ANSP designs, specifies, develops and deploys the VHF infrastructure (possibly through contracts with industrial partners). The ANSP then owns and operates the delivered systems. The ANSP provides the air/ground communication service (VLD2 and ATN routing) to aircraft on the deployed infrastructure. The ANSP may enter into an agreement with CSP(s) to support the AOC traffic on their behalf, and advertised it to aircraft.

F.1 Service Model

F.1.1 Definition of the Service Model

Under the service model, the ANSP contracts with a CSP for VDL service. The CSP deploys, owns and operates the VHF infrastructure. Often the majority of the VHF infrastructure may already be in service to CSP customer aircraft. The CSP obtains and operates the VHF infrastructure per the agreement with the appropriate RF licensing authority. The CSP provides the air/ground communication service (VLD2 and ATN routing) against a regular fee from the ANSP.

F.1.2 Current Situation in Europe

ARINC

ARINC currently provides VDL2 data-link service to the following ANSPs:

Table 18 ANSP customers of ARINC (from D09)

Country	ANSP
Maastricht	MUAC
UK	NATS UK
Ireland	IAA
Denmark	Naviair Denmark
Sweden	LFV Sweden
Czech Republic	ANS CR
Germany	DFS
Austria	Austro Control
Switzerland	Skyguide
Hungary	Hungarocontrol

SITA

SITA has already established ATN/VLD2 service contract with a number of ANSP in Europe, complying with the performance requirements described in the EUROCONTROL document titled "ACSP Generic Requirement Documents". These ANSPs are:

- EUROCONTROL's Maastricht Upper Airspace Centre (MUAC)
- NATS (United Kingdom)
- IAA (Ireland)
- Naviair (Denmark)
- Austro Control (Austria)
- LFV (Sweden)
- Hungarocontrol (Hungary)
- ANS CR (Czech Republic)
- PANSA (Poland).

An overall view is illustrated in Figure 43.

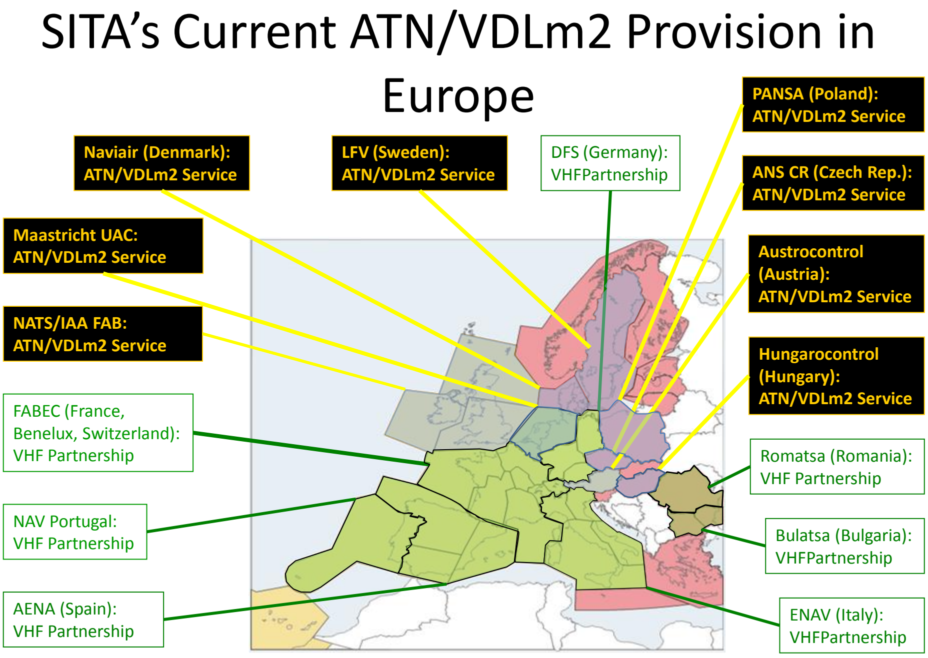


Figure 43 SITA ATN/VDL2 Service Provision in Europe (from D09)

F.1.3 Elements constituting the service

The following Services are usually provided under these ANSP contracts:

- The provision of VDL Mode 2 subnetwork communications services, from the CSP to the ANSP, for the purposes of ATN/VDL2 communications.
- An ATN/VDL2 digital channel for ATC communications via point-to-point air/ground datalink between a controller and an aircraft.
- ATN Ground Network Interfaces connecting the ANSP and ARINC ATN domains.
- Route ATN traffic between ATN-equipped aircraft and the ANSP's ATN/CPDLC end systems.
- The software associated with the ATN service (software deployed on AGRs, BISs, and VGSs).

The CSP will usually:

- Provide all required hardware and software for the VDL2 air/ground network.
- Retain responsibility for the operation and monitoring of VHF ground stations and ATN backbone components.
- Provide training on VGS hardware and maintenance for relevant technical personnel.
- Retain responsibility for the VHF (POA and VDL) frequency licenses.
- Work with the ANSP as needed to implement routing policy, interface protocols, and addressing in accordance with Manual of Technical Provisions for the Aeronautical Telecommunication Network, ICAO Doc 9705 2nd edition and applicable PDRs listed in EUROCAE ED-110B.
- Work with the ANSP to assign specific network addresses for the BIS routers and other relevant parameters prior to the implementation of the service.
- Work with the ANSP to establish the demarcation point between the ANSP and CSP (the point at which the CSP ATN network interfaces with the ANSP ATN network). The demarcation point between the CSP and aircraft domains will be the edge of the aircraft antenna supporting ATN/VDL Mode 2.

The CSP will clarify the details of the ATN/VDL Mode 2 RF coverage:

- RF coverage is usually required at and above a certain Flight Level (e.g. FL 285).
- RF propagation modelling techniques used to establish the coverage footprint of each VDL station at a given altitude.
- Steps taken in the event that the RF coverage proves to be insufficient in practice.
- Details on airspace definition
- Projected RF coverage for each ground station.
- Details on acceptable avionics. For example, CSPs will only allow avionics to use the network if they have passed an acceptable avionics qualification test.
- Description of process used to notify the ANSP about maintenance work and service interruptions.

Qualification

Communication Service Providers must protect their key asset, the air/ground communication infrastructure, by verifying that any customer equipment, and most notably avionics, do behave in a non-detrimental manner when making use of the CSP communication service. In a VLD2 context, this covers inter alia the necessary assurance that the VDL communication protocols are correctly implemented so that there is no undue utilisation of the scarce bandwidth resource.

The process by which such an assurance is built is called in this document the qualification process. Each CSP may use its own internal term (SITA calls it Verification and Qualification – VAQ), but the principle remains unchanged. Any new avionics, or any major change in a previously qualified avionics, is submitted to a series of tests on the CSP test bench, the results of which are duly and formally documented. If these tests are passed, the CSP officially qualifies the tested avionics for use on its own network.

While qualification is a CSP process, it does have a link with the certification of the avionics. Indeed, the documented test results of the qualification performed with the CSPs form a part of the certification case that the avionics manufacturers will submit to the relevant certification Authority (-ies). The CSP qualification does not suffice to obtain the certification, nor does it substitute to it in any way, but constitutes key evidence to the certification authority that the avionics system has been successfully tested with the existing communication networks and satisfies their interoperability requirements.

F.1.4 Pros/Cons

Table 19 Service Model Pros/Cons (from D09)

Topic	Pros	Cons
Specification of the Service	Simplified thanks to the “ACSP’s Generic Requirement Document”	“ACSP’s Generic Requirement Document” is meant as a help to ANSP, but is not mandatory

Topic	Pros	Cons
		Each ANSP may add/define its own requirements, with the risk of customising too much the ATN/VLD2 service.
Certification	CSPs have already a history of service provision. CSPs already have interface validation and verification processes in place. CSPs already have avionics qualification programs in place.	There is no clear European guidelines about the certification of an ATN/VLD2 service provision. Different ANSPs may have different views on the question, thwarting the timely deployment of the service
Acceptance of the Service	CSPs have already a history of service acceptance.	ANSP to adapt validation methods to the planning before the regulatory deadline.
Management	Ease of management for the ANSP, who will not be in charge of directly managing the data link infrastructure CSPs agree to meet the performance parameters associated with the Data Link Mandate. This is usually captured in a Service Level Agreement SLAs) agreed between the CSP and the ANSP. CSPs provide regular reporting on SLA metrics	Evolution of the data link infrastructure governed by the contract between the ANSP and the CSP, may limit the change capacity. CSP will not agree to meet SLAs if necessary resources cannot be controlled by CSPs. For example, a CSP will not be able to guarantee the performance on any shared VDL channel, particularly in terms of transit delay (aka latency).
Owner of the Communication Infrastructure	The CSP is owner	
Deployment Planning - meeting the regulatory deadline	CSPs are able to rapidly deploy new infrastructure to support customer needs. CSP may optimise the network of ground stations over national boundaries, which comes as a cost and time saver to the ANSPs.	Subject to the negotiation and conclusion of a contract between ANSP and CSPIf too many ANSPs issue simultaneous requests to the CSPs, the level of resource may constraint the planning. ANSP requirements, often unclear at the start of the project, may create further delays
ATN Interconnection scenario	Flexible enough to allow different approaches, such as: 1. Direct ATN adjacency to one CSP which also relays ATN traffic to the other CSP 2. Direct ATN adjacency to each CSPs providing the service in the ANSP airspace	The selected ATN interconnection scenario has a direct impact on the level of ATN expertise required from the ANSP The selected ATN interconnection scenario have also an impact to the scope of the service to which the SLA is applicable The ANSP has to contract separately with each CSP, as a CSP may not commit to the service provided by another CSP
Ground Network Interface Standards	CSPs are often able to accept a variety of different ground network interfaces.	

Topic	Pros	Cons
Responsiveness to Change	CSP can rapidly respond to hardware and software changes needed to handle traffic growth and still meet SLAs.	ANSPs have limited ability to control the internal CSP hardware and software upgrade cycles.

F.2 VHF Partnership Model

F.2.1 Definition of the VHF Partnership Model

Air/Ground data link is widely recognised as a key enabler for future ATM concepts. All current long term initiatives, whether SESAR in Europe, NextGen in the United States, or comparable initiatives in other regions of the world, identify data link as a pre-requisite, but also a supporting element of the ATM concepts of the future.

For a number of ANSPs, the air/ground datalink infrastructure belongs naturally to the CNS infrastructure that must be operated and managed in order to fulfil the ANSP's air navigation mission. These ANSPs would not consider it sufficient, from a strategic perspective, to procure the air/ground communication as a service from CSPs. The European Implementing Rule on Data Link Services, mandating CPDLC over ATN/VLD2, further enforces the vision on the mission criticality of the supporting communication infrastructure. In addition, ANSPs view also that the development of their practical know-how on data link can be initiated with the ATN/VLD2 technology.

The VHF partnership model addresses this requirement. In this model, the ANSP procures, deploys, operates and maintains, as part of their CNS infrastructure, the equipment which is necessary to provide ATN/VLD2 air/ground communication.

The ANSP in this context is facing two questions:

- how to design, deploy and validate the ATN/VLD2 communication infrastructure, and at what costs?
- since the network of VLD2 stations will be used by aircraft for both ATC and AOC purpose, what to do with the AOC data captured by the ANSP infrastructure?

A VHF partnership between the ANSP and a CSP is one of the ways to address these two questions. Another way is the development model further described in Paragraph 8.3.4.2.3.

In a partnership model with a CSP, the network of VGS stations is outsourced by the CSP to the ANSP. It regards the whole network of VGS stations, including both POA and VLD2 radios, as these radios are closely intertwined on the same VHF stations. Furthermore, the ACARS base frequency plays a key role in advertising the presence of VLD2 to aircraft, and must therefore be available alongside VLD2-equipped VHF stations.

In addition to the network of stations, the ANSP may also acquire from the CSP additional elements such as the monitoring systems necessary to manage the VHF stations, the ATN routers, logs and traces analysis tools, and VLD2 frequency monitoring tools (see further in Paragraph 8.3.4.2.2.3). In turn, the CSP grants the ANSP the use of its data link label, thereby enabling customer airlines to connect to the ANSP air/ground network.

The outsourcing of the existing infrastructure may also include the additional equipment necessary to augment the level of the service, for example the VLD2 coverage, and put it in line with the requirements coming from the Implementing Rule. This would in practice regard an additional number of VLD2 radios and or stations, and base ACARS frequency radios necessary to advertise the presence of the VLD2 service. The ANSP is in charge of obtaining the required frequency licenses.

Regarding the AOC service, the partnership agreement will cover the conditions under which the ANSP infrastructure will relay AOC data from/to aircraft. These conditions fall into two categories:

- Technical: the AOC data, using ACARS protocols, will be relayed between the ANSP and the CSP through a gateway between their respective ground networks. The CSP will remain responsible for the switching of ACARS messages, while the CSP becomes responsible for the operation of the VHF stations covering its airspace, as well as airport sites. Since CSPs commit to an SLA with airlines on AOC data, this SLA will be in turn translate in an SLA between the ANSP and the CSP, governing the AOC data exchanges.
- Commercial: in a partnership model, the CSP provides its billed AOC service to airlines using the ANSP infrastructure. The CSP will therefore contribute to the ANSP costs by remitting a fee which will usually be determined on the basis of the volume of AOC data transiting on the ANSP infrastructure

The establishment of a CSP/ANSP partnership must not result in any break in the seamless service, AOC or ATC, provided to airlines. Indeed, CSPs are being contracted by airlines on a global basis, hence the communication service must not be provided in piecemeal manner, or limited by the boundaries between difference airspaces.

In the ATN/VDL2 context, the seamless nature of the service can be endangered if no proper attention is paid to which VDL2 station an aircraft acquires at any time. Indeed, the implementation of the VLD2 protocol in avionics is such that it is difficult to predict which VDL2 station an aircraft captures at any moment. The captured station to exchange CPDLC data with the partner ANSP could as well be a station operated by that ANSP or a station operated by the CSP or another ANSP partner.

The partnership agreement will also cover these points by:

- Allowing the CSP to retain a passive monitoring of the partner ANSP stations. This in turns makes it possible for the CSP to ensure continued service monitoring to the airlines.
- Defining the applicable ATN routing policies between the CSP and the partner ANSP. This in turns makes it possible for aircraft connected to the CSP service label, to perform CPDLC logons regardless of the status of the captured ground station.

F.2.2 Current Situation in Europe

SITA

If the CSP is SITA, the current situation in Europe is illustrated in

VHF partnerships have been established with:

- ENAIRE (Spain)
- DFS (Germany)
- DSNA (France)
- Skyguide (Switzerland)
- NAV Portugal (Portugal)
- Romatsa (Romania)
- Bulatsa (Bulgaria)

For all these ANSPs, SITA provided an upgraded network of VHF stations, covering both the ATC needs (performance requirements of the Implementing Rule on Data Link Services), and the AOC needs (SLAs back-to-back with airlines requirements). SITA also provided the station monitoring tools. For some of these ANSPs, SITA provided also the ATN routers. For some others, SITA provided the log and trace analysis tools, and the VLD2 frequency monitoring tools.

ARINC

ARINC has not, at this stage, entered into any partnership model.

F.2.3 Elements constituting the partnership model

As introduced earlier, the VHF partnership between a CSP and an ANSP may comprise different components.

- As a minimum, the VHF partnership would comprise:
  1. the handover/supply of the network of VLD2 stations necessary to cover the airspace under the ANSP authority, in a way that complies with the performance requirements of the Implementing Rule. If the CSP already operated VLDm2 stations in that airspace, these will be transferred to the ANSP. If needed, additional VLD2 stations will be provided to complete the coverage. All these stations comprise also radios in the POA base frequencies
  2. the handover of the existing network of POA stations
  3. the provision of the monitoring systems for the VHF stations
  4. the installation of a network gateway (usually at IP level) between the CSP network and the ANSP network. This gateway will be designed in such a way that is does not degrade neither the ATC ATN service neither the ACARS service
  5. the definition of the IP and ATN routing policies applicable at the gateway to allow seamless AOC and ATC traffic, as well as passive monitoring by the CSP of the ANSP VHF stations
  6. the definition of the mutual SLA applicable both for AOC traffic
  7. the description of how the CSP contributes to the satisfaction of the performance parameters associated with the Data Link Mandate
  8. the installation of the existing stations and any new station on the ANSP own ground communication network, and in the ANSP premises.

- Optionally, the VHF partnership may include, subject to the ANSP choice:
  9. the provision of ATN routers to the ANSP, A/G and/or G/G. This will depend upon the choice of the ANSP to perform its own ATN A/G routing, or to let if done by the CSP, or in the future, by a regional entity. It has to be noted in that regard that the EUROCONTROL Link2000+ Programme had warned against the proliferation of ATN A/G routers, pointing at a risk of routing inefficiencies and a too high level of routing updates consuming precious network resources (this is documented in ref. [15];
  10. the provision of VLD2 frequency monitoring systems. This include VLD2 receiver to capture all the traffic making use of the VLD2 frequency(-ies) in the ANSP airspace, and associated tools to capture and analyse such logs;
  11. the provision of test tools and platform. This may include a test bench reproducing each element of the operational chain. It may also include special tools able to build a database of logs created by the various elements of the end-to-end communication chain (VHF stations, ATN routers, monitoring system, etc.) and to query that database.

F.2.4 Pros/Cons

In the following table, the pros and cons of a VHF partnership are discussed relative to the ANSP perspective.

Table 20 Partnership Model Pros/Cons (from D09)

Topic	Pros	Cons
Specification of the VHF Partnership	The ANSP is in full control, although it may use the “ACSP’s Generic Requirement Document”, ref. [16] published by the EUROCONTROL Link programme	Each ANSP will have to define the infrastructure it needs, compute coverage to put in line with the requirements of the data link mandate Each ANSP will have to consider the

Topic	Pros	Cons
	as a means to understand the scope of the communication service	certification requirements
Certification	Systems are delivered to an ANSP, hence the certification framework is defined by EC 552/2004	Compared to the Service - Model, the ANSP will be facing all certification requirements
Management	The ANSP may delve on the CSP experience and tools to manage the communication infrastructure	Compared to the service model, the ANSP is in full control and management of the communication infrastructure The ANSP has to commit to SLAs with the CSP
Acceptance	Acceptance of systems, similar to a usual CNS/ATM project	ANSP have to specify the validation process
Owner of the Communication Infrastructure	The ANSP is owner	
Deployment Planning – meeting the regulatory deadline	All partnership constituents are existing and field proven systems, may be delivered in a rapid tempo	ANSP are entirely in charge of the planning, including NSA certification
ATN Interconnection scenario	ANSP is fully in charge of the ATN traffic in its airspace	Still necessary to contract ATN backbone service with partner CSP to ensure seamless service to aircraft at the airspace boundary Provision of A/G router by a CSP partner increase the issues of A/G router proliferation
Support to VDL Multi-Frequency	ANSP is in full control of multi-frequency deployment, deciding where and when additional frequencies are required to maintain the level of service for ATC and AOC	The ANSP has to deploy the means and develop the capacity to constantly monitor VLD2 frequency (-ies) usage and grade of service.

F.3 Development Model

In the Development Model an ANSP specifies, designs, develops and deploys the DL infrastructure (possibly through contracts with industrial partners) maintaining the full responsibility for the ATS provision as required by IR 29/2009 and IR 310/2015.

Furthermore, the ANSP is easily able to provide the Declaration of Verification to the NSA according to the EC 552/2004 (EATM Interoperability Regulation) and following the ETSI EN 303214 (Data Link Services (DLS) System: Requirements for ground constituents and system testing).

The ANSP owns and operates the DL overall system that is composed by:

- RF network (VLD2)
- ATN routing network
- ANSP ground/ground transport network
- CSP network interfaces
- ATM sub-system
- Network Support Systems (Network Management, Performance Management, Recording and AOC Billing Systems)

Regarding the AOC, the ANSP has to enter into an agreement with CSP(s) to support the AOC traffic on their behalf and advertise it to aircraft.

The following Figure 44 describes the Development Model.

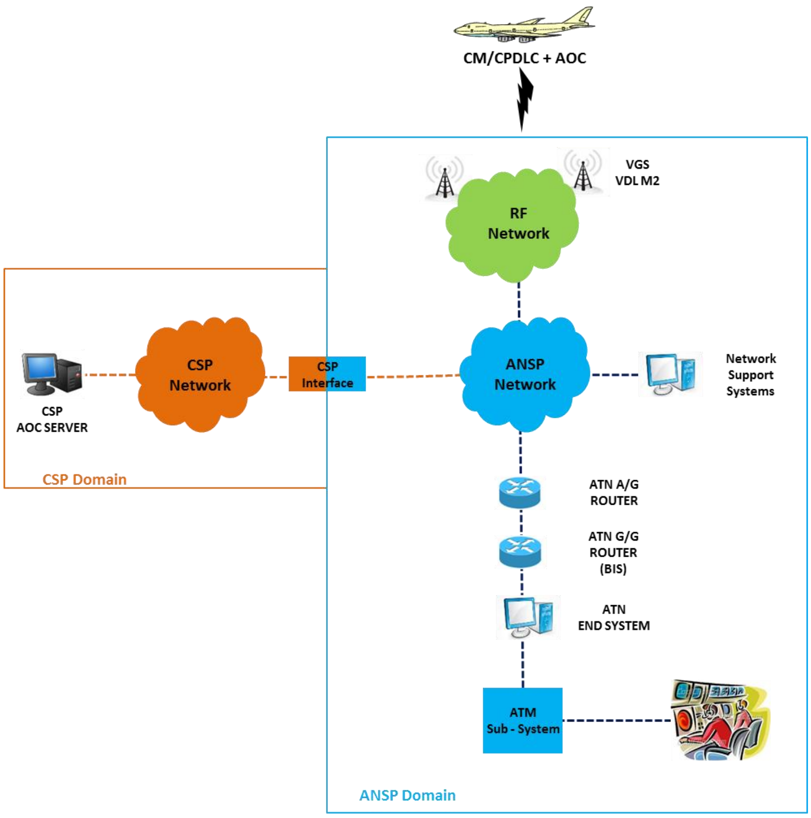


Figure 44 Development Model (from D09)

F.3.1 Definition of the Development Model

In this paragraph the "development model" is described.

This model can be implemented by any ANSP and, currently, it is implemented in Italy by ENAV. So, there is the opportunity to go through the description of a system already in operation.

Considering that it has been decided to use the ATN/VLD2 and furthermore, that aircraft shall be equipped with only one VDL data M2 radio, consequently the same RF channels shall be shared between ATN DLS and AOC even if they have different performance requirements. Then, all DLS systems shall be able to manage both ATS over ATN and AOC.

The Italian DL system, composed by ATM segment plus COM network (Ground – Ground and Air –Ground segments), has been specifically developed in order to satisfy the ATN DLS requirements including safety and security ones. Of course, also AOC shall be accommodated at transport level.

The "development model" main requirements are:

- Compliance with IR 29/2009 and 310/2015
- Compliance with Regulation EC 552/2004 (EATM system interoperability)
- Compliance with other applicable documents
- QoS for ATN DLS "like A/G Voice"
- VGS number minimisation
- ATS messages prioritisation
- ATN AGR and GGR number optimisation
- Providing DLS (AOC + ATS) in selected Airports and En-route
- MF scalability

In details:

Compliance with IR 29/2009 and 310/2015

As required, the DL system will provide the DLS to all aircraft:

- ARINC customers
- SITA customers
- None of Above, e.g. non-AOC aircraft

In order to support ARINC and SITA customers, the ANSP in the Development Model has to enter in a specific agreement with SITA and ARINC, both AOC and ATC.

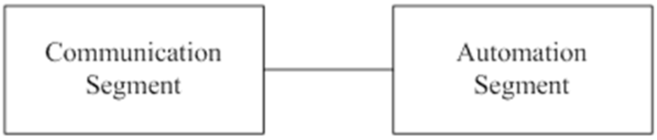
Compliance with other applicable documents

- ICAO annexes
- ETSI standards
- Link 2000+ recommendations
- Eurocae ED 120 and ED 110
- industrial standards
- others

QoS for ATN DLS "like A/G Voice"

Having the ANSP the full responsibility of the ATS provision, an ANSP could decide to take as reference the voice service levels also for DL ATS in terms of E2E performances.

For example, in the Italian DL system, the DLIC, ACM and AMC end-to-end calculated availability, obtained by COM and Automation segments, is shown in the following Figure 8-13.



	Intrinsic Availability	Operative Availability	Unavailability time in a year (in hours)
Automation Segment	99,99956363%	99,99575799%	0,37

DLIC, ACM and AMC availability (Automation Segment)

	Intrinsic Availability	Operative Availability	Unavailability time in a year (in hours)
Communication Segment	99,99999750%	99,99984032%	0,013987785

DLIC, ACM and AMC availability (Communication Segment)

	Intrinsic Availability	Operative Availability	Unavailability time in a year (in hours)
Overall Service	99,99956114%	99,99559831%	0,3856

DLIC, ACM and AMC availability (Overall)

Figure 45 DLIC, ACM and AMC Availability (from D09)

VGS number minimisation

Unavoidably a large number of VGS in one or more RF VLD2 networks implies:

- hidden terminal issues: multiple VGS deployment, using CSMA, causes many “hidden terminal” scenarios producing uplink packet collisions with consequent latency increase and bandwidth reduction;
- interferences both between VLD2 GS and VLD2 GS and between VLD2 GS and analog A/G GS: the independent and uncorrelated deployment of different GSs of different CSPs, even without any consideration of analog A/G voice systems, increases the probability of uplink packet collisions.

The GS number can be minimised by:

- implementing ONLY ONE RF NETWORK
- identifying the best installation sites for airports and en-route coverage mainly evaluating the EMC (Noise, Blocking and Intermodulation effects)
- implementing the Dual Squitter functionality

By this functionality, the same RF network allows the link establishment and/or link handoff for all aircraft: ARINC customers, SITA customers and “none of them”. To do this, the VGSs transmit the GSIF frames alternatively with SITA and ARINC identification code.

However, the necessity to accommodate AOC needs may require additional stations or sites compared to what would be strictly needed for ATC coverage.

The “Only one RF Network for CSP1, CSP2 and “none of them” Users” concept is shown in the following Figure 46.

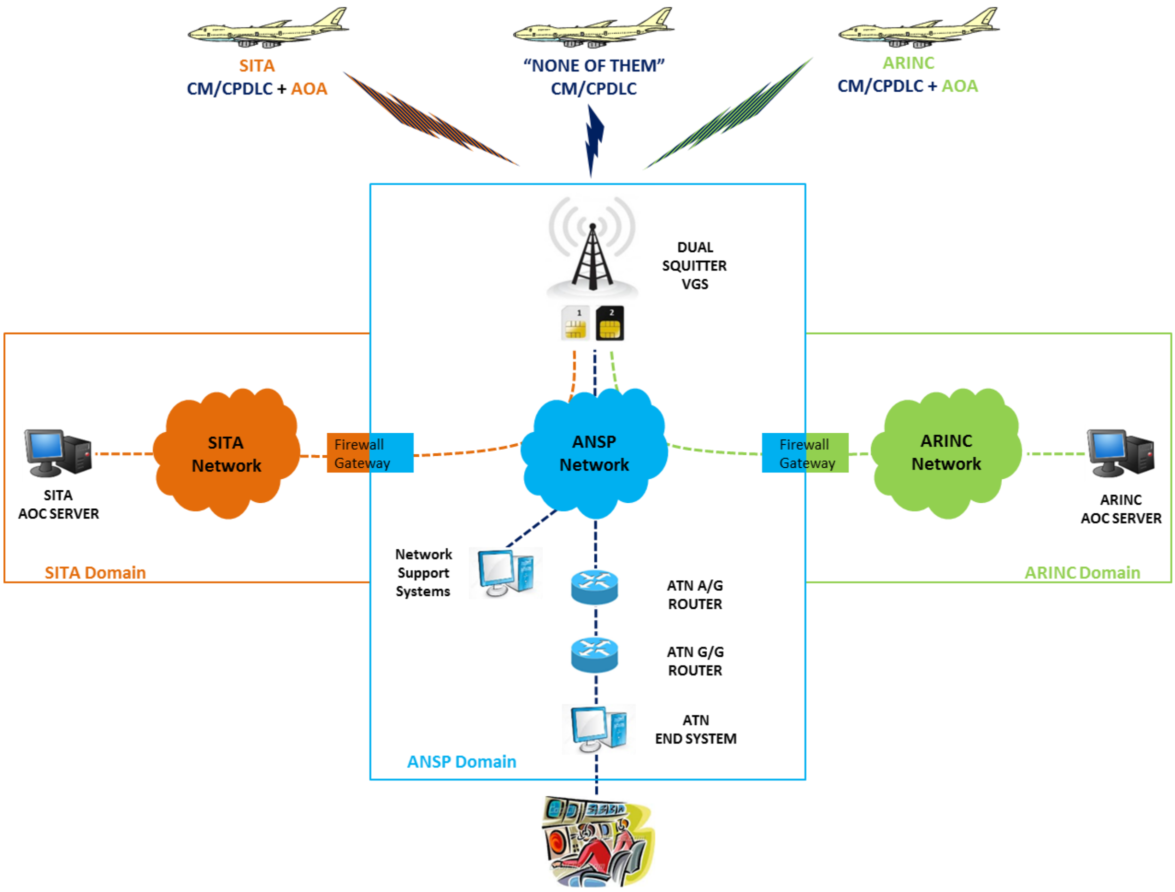


Figure 46 Dual Squitter Mechanism (from D09)

ATN AGR and GGR number optimisation

In order to reach the required ATS performance levels (for example, in terms of continuity of service, availability, safety,…) an optimised ATN architecture has been implemented with double RF layers (Main 1 + Main 2) using only two ATN AGR and two ATN GGR cross-connected as shown in Figure 47.

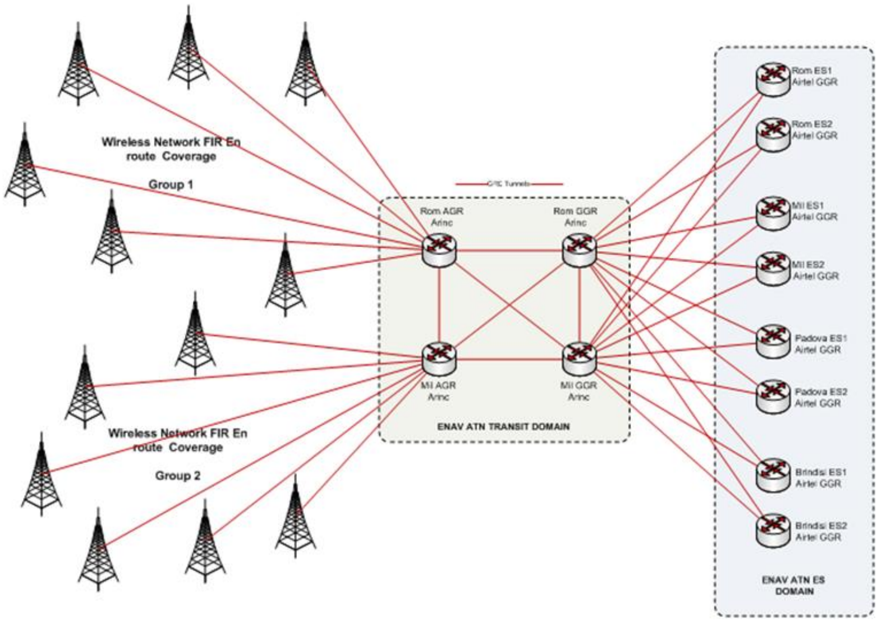


Figure 47 Optimised ATN Architecture (from D09)

In principle, the EUROCONTROL LINK programme recommended, in reference [15], to limit the number of ATN AGR routers at the European level. Indeed, the proliferation of ATN AGR routers has a negative impact on the routing efficiency.

Provide DLS (AOC + ATS) in selected Airports and En-route

In deploying the unique RF network, an integrated approach has been followed in order to optimise the RF coverage taking into account both the EN-route mandatory IR requirements and the commercial AOC service as required by airline needs.

Indeed, where possible, the preferred VGS location is in the airport to guarantee the best coverage at GND but also in EN-Route at the same time (another contribution to minimise the VGS number).

MF scalability

In order to face the different operational needs in different regions of an ANSP responsibility area, the Multi Frequency DL system has been designed to manage a different frequencies number according to the local level of traffic in that relevant area (as a volume of airspace which normally presents a quite low number of flights does not require the same amount of data communications capacity as a big airport).

In this way the system is scalable enough to permit of handling efficiently each case, leaving constant the level of its performance.

This approach allows easy upgrading of the overall system capacity with new frequencies introduction.

In fact, it is possible to add only one new frequency each time the available bandwidth becomes insufficient even in only one area (the number of frequencies “linearly” grows with the traffic increase).

The overall system is able to manage a different number of frequencies in different areas.

F.3.2 Current Situation in Europe

The Development Model is currently implemented in Italy by ENAV.

F.3.3 Elements constituting the development model

According to ETSI EN 303214 (Data Link Services (DLS) System: Requirements for ground constituents and system testing), the Development Model for ATN covers two domains:

- ATSP Domain
- CSP Domain

Figure 48 illustrates the components of each domain.

Those components have to be considered as a baseline in order to provide the Declaration of Verification to the NSA according to the EC 552/2004 (Interoperability Regulation).

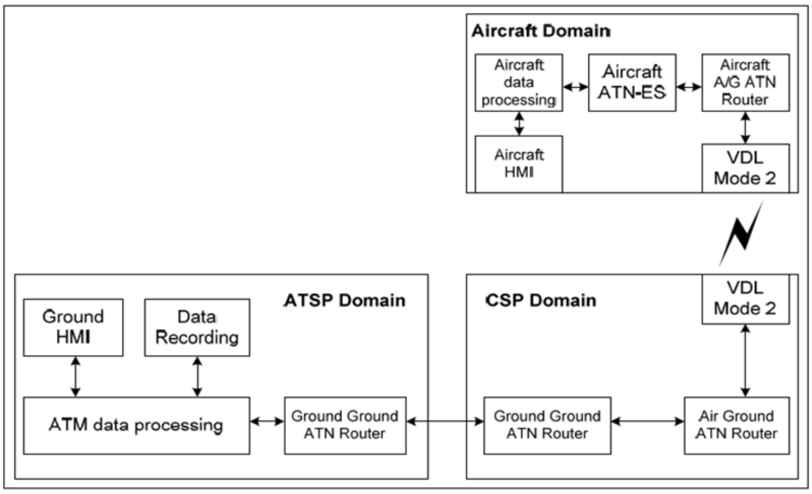


Figure 48 ETSI EN 303214 Domains (from D09)

With regard to the DLS service provision, the Development Model presents the following additional components:

- Firewall-Gateway as interface between ANSP and CSP networks (for AOC service provision)
- Network Support System composed by

1. Network management
2. Performance Management
3. Recording System
4. AOC Billing Systems.

F.3.4 Pros/Cons

Table 21 Development Model Pros/Cons (from D09)

Topic	Pros	Cons
Architecture	"Only one RF network" optimises the VLD2 implementation	Disparate ANSP implementations must consider bordering RF networks
Specification of the Partnership	The specification of the Partnership is required only for AOC transport;	There is a limited number of GSIFs that can be used and

Topic	Pros	Cons
	The partnership for AOC is a private agreement and there is no regulation to be applied; No need of particular requirements on the AOC coming from ANSP;	understood by avionics. Additional CSPs cannot, at this stage, issue their own GSIF, but have to make use of the SITA, and/or ARINC GSIFs.
Certification	As the ANSP is the owner and the operator of the DL network, it has the full responsibility (technical and operational) for the provision of ATS. This can be done in a similar way of other CNS/ATM systems.	The ANSP is responsible for the whole certification and can only rely on the EC 552/2004 documentation related to the systems provided by the suppliers.
Management	As the ANSP is the owner and the operator of the DL network, it has the full responsibility in managing in house the network, in terms of: 1. Service monitoring 2. System monitoring 3. Technical issues 4. Maintenance 5. System upgrading 6. Further deployments (example: MF)	
System acceptance	System acceptance is similar to an usual CNS/ATM system applying the consolidated ANSP internal procedures The ANSP technical and operational validation processes are already in place	In the Development model, the ANSP operates the infrastructure on the basis if the systems it developed. There is always a new risk when validating or certifying new systems
Owner of the Communication Infrastructure	The ANSP is owner	
Deployment Planning – meeting the regulatory deadline	ANSPs are entirely in charge of the planning, including the DoV emission. So, no needs to interface other subjects for the DL system deployment then the ANSP is fully responsible for managing the deadlines.	Any new technical effort by an organisation with no previous experience is a risk, in particular regarding schedule
ATN Interconnection scenario	The Development Model is in line with standards and it can be interfaced with other neighbour systems through BIS routers.	It is not regulated the transport G/G internetworking between different ATN service providers (this is a general issue for different system models). It is not regulated the VGS deployment between different RF networks and frequency coordination between States even if it is recommended by ICAO in Annex 10 ATT I-4 para 4.5.2 (this is a general issue for different system models).
Support to VDL Multi-Frequency	Ease of Transition (easy upgrading of the overall DL system capacity with new frequencies introduction) Scalability: it is possible to add only one new frequency each time the available	

Topic	Pros	Cons
	bandwidth becomes insufficient even in only one area (the number of frequencies “linearly” grows with the traffic increase)	
Safety	Directly managed by ANSP according to its own procedures	
Security	Directly managed by ANSP according to national policies	

G Multi-Frequency Deployment Strategy

This annex has been taken from D09, Section 7.3.7.

The basic concept of MF deployment strategy is to incrementally add new channels, as needed, in areas where VDL2 traffic load increase over a defined threshold, with the aim to maintain the system performances within the requirements.

Alternate VDL2 channels are allocated for specific function, providing connectivity service to aircraft depending on their position: on ground or en-route.

Currently airports terminal (APT) coverage is needed for AOC services, this means that the main driver for the infrastructure deployments are the Airlines requirements vs. CSPs, that will take into account to provide VDL2 coverage on each site requested.

Since roughly 50% of VDL2 traffic is performed on terminal areas, segregating ground aircraft will results to an indirect benefit also for ENR users (ATS and AOC), reducing the hidden terminals effect.

A different approach should be used to deploy ENR coverage, where the selection for the most appropriate sites should be made considering to maintain to a minimum the VGS number involved, but at the same time to provide the required availability for the ATS safety critical services.

NOTE: A detailed, site by site, radio coverage propagation study should be performed to deploy the most efficient ENR coverage network.

A special attention should be used to assure CSC coverage over each VDL2 served areas, either for network management and for recovering/emergency functions, this means that wherever an alternate VDL2 frequency will be deployed a CSC coverage, at least for the same area, must be provided.

The above basic considerations are valid both for shared and dedicated channels allocation and are focused on VGS distribution optimisation.

G.1 Multi Frequency Transitions Considerations

To achieve an efficient VDL2 MF network, terminal coverage should be provided to each airport with dedicated APT channel(s) and only particular sites should be selected to deploy ENR channel(s). Reducing the number of VGS used to provide ENR coverage may be the most beneficial optimisation in the RF network but some considerations about expected transitions behaviour should be verified.

Despite the number of channels and their CSP/GSIF related allocation (single or dual) we may assume to have four basic MF VGS configuration, as in the table below.

Table 22 Basic MF VGS configurations

ID	VGS / Site function	CSC	APT	ENR
1	Airport VGS	YES	YES	NO
2	En-Route and Airport VGS	YES	YES	YES
3	En-Route VGS	YES	NO	YES
4	Light traffic area only CSC VGS	YES	NO	NO

G.1.1 Airport VGS

In this type of sites there is the requirement to provide APT coverage for the airport but is not a selected site for ENR coverage, so the VGS will be configured with a CSC channel and APT channel(s). The following behaviour could be expected

- **Departing aircraft:** In this case at power up the aircraft will attempt a connection to the CSC and then will be moved to the APT channel (some aircraft may start directly connecting to the APT channel if this was the last channel used before power down). After take-off there are the following possibilities:
  1. A/C could be moved, by the ground system, on CSC of the same VGS where will hear GSIF of other VGS supporting ENR channels.
  2. A/C could be moved to an ENR frequency configured for that area, but in that case the origin VGS may not know the operational status for other VGS supporting the ENR channel, so a centralised management systems should coordinate the Autotune procedure.
- **Arriving aircraft:** In this case the aircraft should arrive linked to an ENR channel unable to hear the destination airport VGS, here there are the following possibilities:
  1. During the approach/landing aircraft will lose ENR channel signal and automatically recover on CSC, then will hear the destination airport VGS and perform a link establishment, after landing will be moved on the APT channel.
  2. The CSP before to lose connection with the aircraft on the ENR channel will retune back the aircraft to CSC of the same VGS, this will allow a smoother HO to the CSC of the destination airport VGS. (this approach is the same used for CSP interoperability support and could be reused without additional implementations)
- **Overflying aircraft:** In this case no particular interaction is foreseen with airport VGS since the aircraft should be on ENR channels.

G.1.2 En-Route and Airport VGS

In this type of sites there is the requirement to provide APT coverage for the airport and the same VGS is selected to provide ENR coverage, so the VGS will be configured with a CSC, ENR and APT channels. The following behaviour could be expected

- **Departing aircraft:** In this case at power up the aircraft will connect to CSC and then will be moved to APT channel (some aircraft may start directly connecting to the APT channel if this was the last channel used before power down). After take-off the aircraft will be moved on ENR channel for the en-route flight phase.
- **Arriving aircraft:** In this case the aircraft should arrive linked to VGS ENR channel on the destination airport, after landing the aircraft will be moved on APT channel for ground operations.
- **Overflying aircraft:** In this case the aircraft will use the ENR coverage of the VGS, and there are the following possibilities:
  1. The aircraft arrive already on ENR channel, so just normal HO operation is required.
  2. The aircraft arrive on CSC channel, so in that case the VGS should move the a/c on the ENR channel.

<u>Recommendations</u>

- ENR and CSC radios should be operated with the same emitting power, required for the en-route coverage. This is necessary to guarantee CSC coverage among all the VGS operational area.

G.1.3 En-Route VGS

In this type of sites there is the requirement to provide only ENR coverage, so the VGS will be configured with a CSC and ENR channel. The following behaviour could be expected

- Departing aircraft: Not applicable, since this configuration is it not suitable for airport sites. But in case, the aircraft on terminal area will use CSC to exchange VDL2 traffic. Once departed will be moved from CSC to ENR channel.
- Arriving aircraft: Not applicable, since this configuration is it not suitable for airport sites. But in case, the aircraft will arrive linked to an ENR channel and once landed will be moved to CSC for ground operations.
- Overflying aircraft: In this case the aircraft will use the ENR coverage of the VGS, and there are the following possibilities:
  1. The aircraft arrive already on ENR channel, so just normal HO operation is required.
  2. The aircraft arrive on CSC channel, so in that case the VGS should move the a/c on the ENR channel.

Recommendations

- ENR and CSC radios should be operated with the same emitting power, required for the en-route coverage. This is necessary to guarantee CSC coverage among all the VGS operational area.
- This configuration should not be used on airport sites, otherwise aircraft on ground will use CSC to exchange VDL2 traffic, increasing the hidden terminal effect for the en-route area.

G.1.4 Light traffic area only CSC VGS

In this type of sites only CSC channel will be operated, in that case all the managed aircraft, either en-route and in terminal area, will be connected using the CSC.

Recommendations

- To use this configuration only in very light traffic areas and where the CSC coverage do not overlap with the CSC of an area with high traffic requirements.

G.2 MF Deployment Scenario (2018)

Based on the information provided by ELSA partners (CSPs) the following MF scenario is envisaged in the short term evolution (2018).

NOTE: The following scenario is only to be used for the purposes of VDL MF WA2 research within the context of ELSA. It is not a projection of traffic volumes or traffic patterns and should not be considered as such. It is not a commitment for deployments.

G.2.1 ARINC Network short term MF evolution (2018)

The following Table shows the short term MF evolution envisaged by ARINC for the VDL2 network.

Table 23 ARINC MF 2018 - VGS Distribution and Frequency Allocation (from D09)

2018 MF ARINC Network - VGS Distribution and Frequency Allocation								
CODE	**SITE**	**COUNTRY**	**POSITION**		**GSIF**	**2018**		
			LAT	LON	Adv. Net	F1	F2	F5
AMS	Amsterdam	Netherlands	52.30	4.77	ARINC	CSC	APT	ENR
BER	Berlin	Germany	52.36	13.50	ARINC	CSC	APT	ENR
BES	Brest	France	48.43	-4,42	ARINC	CSC		ENR
BOD	Bordeaux	France	44.82	-0,7	ARINC	CSC		ENR
BRU	Brussels	Belgium	50.88	4.47	ARINC	CSC	APT	ENR

CDG	Paris	France	49.00	2.58	ARINC	CSC	APT	ENR
CGN	Cologne	Germany	50.87	7.12	ARINC	CSC		ENR
DRS	Dresden	Germany	51.12	13.75	ARINC	CSC		ENR
FRA	Frankfurt	Germany	50.00	8.58	ARINC	CSC	APT	ENR
GVA	Geneva	Switzerland	46.22	6.10	ARINC	CSC	APT	ENR
HAM	Hamburg	Germany	53.62	9.98	ARINC	CSC		ENR
LGW	London	United Kingdom	51.15	-0,15	ARINC	CSC	APT	ENR
LHR	London	United Kingdom	51.47	-0,42	ARINC	CSC	APT	ENR
MRS	Marseille	France	43.43	5.21	ARINC	CSC	APT	ENR
MUC	Munich	Germany	48.35	11.78	ARINC	CSC		ENR
NCE	Nice	France	43.65	7.20	ARINC	CSC	APT	ENR
NTE	Nantes	France	47.15	-1,6	ARINC	CSC		ENR
NUE	Nuremberg	Germany	49.50	11.05	ARINC	CSC		ENR
ORY	Paris	France	48.72	2.35	ARINC	CSC	APT	ENR
STR	Stuttgart	Germany	48.68	9.22	ARINC	CSC		ENR
TLS	Toulouse	France	43.62	1.37	ARINC	CSC		ENR
VIE	Vienna	Austria	48.12	16.55	ARINC	CSC		ENR
ZRH	Zurich	Switzerland	47.45	8.55	ARINC	CSC	APT	ENR
PRG	Prague	Czech Republic	50.10	14.26	ARINC	CSC		
BLL	Billund	Denmark	55.74	9.15	ARINC	CSC		
CPH	Copenhagen	Denmark	55.61	12.65	ARINC	CSC		
LYS	Lyon	France	45.72	5.09	ARINC	CSC		
BUD	Budapest	Hungary	47.43	19.25	ARINC	CSC		
BLY	Dooncarton	Ireland	54.27	-9,83	ARINC	CSC		
BYT	Schull	Ireland	51.55	-9,54	ARINC	CSC		
DUB	Dublin	Ireland	53.42	-6,25	ARINC	CSC		
OSL	Oslo	Norway	60.19	11.10	ARINC	CSC		
BCN	Barcelona	Spain	41.29	2.07	ARINC	CSC		
MAD	Madrid	Spain	40.49	-3,56	ARINC	CSC		
ARN	Stockholm/Arlanda	Sweden	59.65	17.93	ARINC	CSC		
KSD	Karlstad	Sweden	59.44	13.33	ARINC	CSC		
OSD	Ostersund	Sweden	63.19	14.50	ARINC	CSC		
RNB	Ronneby	Sweden	56.26	15.26	ARINC	CSC		
IST	Istanbul	Turkey	40.97	28.82	ARINC	CSC		
ABZ	Aberdeen	United Kingdom	57.20	-2,2	ARINC	CSC		
BRS	Bristol	United Kingdom	51.38	-2,71	ARINC	CSC		
GSY	Normanby Le Wold	United Kingdom	53.45	-0.2931	ARINC	CSC		
LSI	Sumburgh	United Kingdom	59.87	-1,2	ARINC	CSC		
MAN	Manchester	United Kingdom	53.35	-2,27	ARINC	CSC		
NCL	Newcastle	United Kingdom	55.03	-1,7	ARINC	CSC		

The following Figure shows the detail of the APT VGS deployment.

Figure 49 ARINC Short term (2018) APT VGS distribution (from D09)

The following Figure reports the details of the ENR VGS distribution.

Figure 50 ARINC Short term (2018) ENR VGS distribution (from D09)

G.2.2 ENAV Network short term MF evolution (2018)

The following Table shows the short term MF evolution envisaged by ENAV for the VDL2 network.

Table 24 ENAV MF 2018 - VGS Distribution and Frequency Allocation (from D09)

2018 MF ARINC Network - VGS Distribution and Frequency Allocation							
CODE	**SITE**	**COUNTRY**	**POSITION**		**GSIF**	**2018**	
			LAT	LON	Adv. Net	F1	F2
AOH	Alghero	Italy	40,6298	8,29492	ARINC	CSC	
BRI	Bari	Italy	41,136	16,7668	ARINC / SITA	CSC	
BGY	Bergamo	Italy	45,665	9,70268	ARINC	CSC	
BLQ	Bologna	Italy	44,5356	11,2994	ARINC / SITA	CSC	
BDS	Brindisi	Italy	40,6588	17,9405	ARINC / SITA	CSC	

CAG	Cagliari	Italy	39,2555	9,05775	ARINC / SITA	CSC	
QCZ	Caraffa	Italy	38,8762	16,4811	ARINC	CSC	
CTA	Catania	Italy	37,4628	15,05	ARINC / SITA	CSC	
LIN	Milano Linate	Italy	45,4614	9,28057	ARINC / SITA	CSC	APT
MXP	Milano Malpensa 1	Italy	45,6208	8,73004	ARINC / SITA	CSC	APT
NAP	Napoli	Italy	40,8794	14,2855	ARINC / SITA	CSC	
OLB	Olbia	Italy	40,9018	9,51415	SITA	CSC	
CIA	Roma Ciampino	Italy	41,8038	12,5835	ARINC	CSC	
FCO	Roma Fiumicino 1	Italy	41,8164	12,2643	ARINC / SITA	CSC	APT
FCO	Roma Fiumicino 2	Italy	41,8078	12,2492	ARINC	CSC	
TRN	Torino Caselle	Italy	45,1977	7,64577	ARINC	CSC	
UST	Ustica	Italy	38,7076	13,1775	ARINC / SITA	CSC	
VCE	Venezia Tessera	Italy	45,5104	12,3471	ARINC / SITA	CSC	APT
MXP	Milano Malpensa 2	Italy	45,6256	8,7395	ARINC	CSC	

The following Figure reports the detail of the APT VGS deployment.

Figure 51 ENAV Short term (2018) APT VGS distribution (from D09)

G.2.3 SITA Network short term MF evolution (2018)

The following Table shows the short term MF evolution envisaged by SITA for the VDL2 network.

Table 25 SITA MF 2018 - VGS Distribution and Frequency Allocation (from D09)

2018 MF SITA Network - VGS Distribution and Frequency Allocation								
CODE	SITE	COUNTRY	POSITION		GSIF	F1	F2	F3
			LAT	LON	Adv. Net			
ABZ	Aberdeen	United Kingdom	57.20	-2,2	SITA	CSC		
ACE	Arrecife	Spain	28.95	-13,6	SITA	CSC		
AGP	Malaga	Spain	36.67	-4,47	SITA	CSC		
ALC	Alicante	Spain	38.28	-0,57	SITA	CSC		

AMS	Amsterdam	Netherlands	52.30	4.77	SITA	CSC	ENR	APT
ARN	Stockholm	Sweden	59.65	17.93	SITA	CSC	ENR	APT
ATH	Athens	Greece	37.92	23.92	SITA	CSC		APT
BCM	Bacau	Romania	46.52	26.91	SITA	CSC		
BCN	Barcelona	Spain	41.30	2.07	SITA	CSC	ENR	APT
BES	Brest	France	48.43	-4,42	SITA	CSC	ENR	
BHX	Birmingham	United Kingdom	52.45	-1,72	SITA	CSC		
BIO	Bilbao	Spain	43.30	-2,92	SITA	CSC		
BLL	Billund	Denmark	55.73	9.13	SITA	CSC		
BLQ	Bologna	Italy	44.52	11.28	SITA	CSC	ENR	
BOD	Bordeaux	France	44.82	-0,7	SITA	CSC	ENR	
BOJ	Burgas	Bulgaria	42.57	27.51	SITA	CSC		
BRE	Bremen	Germany	53.03	8.78	SITA	CSC		
BRR	Barra	United Kingdom	57.00	-7,5	SITA	CSC		
BRS	Bristol	United Kingdom	51.38	-2,7	SITA	CSC		
BRU	Brussels	Belgium	50.88	4.47	SITA	CSC		APT
BUD	Budapest	Hungary	47.43	19.25	SITA	CSC	ENR	
CDG	Paris	France	49.00	2.58	SITA	CSC	ENR	APT
CFU	Corfu	Greece	39.60	19.90	SITA	CSC		
CGN	Cologne	Germany	50.87	7.12	SITA	CSC		
CLJ	Cluj Napoca	Romania	46.78	23.68	SITA	CSC		
CND	Constanta	Romania	44.36	28.48	SITA	CSC		
CPH	Copenhagen	Denmark	55.62	12.63	SITA	CSC	ENR	APT
DBV	Dubrovnik	Croatia	42.55	18.27	SITA	CSC	ENR	APT
DRS	Dresden	Germany	51.12	13.75	SITA	CSC		
DTM	Dortmund	Germany	51.50	7.60	SITA	CSC		
DUB	Dublin	Ireland	53.42	-6,23	SITA	CSC	ENR	
DUS	Dusseldorf	Germany	51.27	6.75	SITA	CSC		APT
EDI	Edinburgh	United Kingdom	55.93	-3,35	SITA	CSC		
EFL	Argostonlion	Malta	38.12	20.50	SITA	CSC		
ERF	Erfurt	Germany	50.97	10.95	SITA	CSC		
FAB	Farnborough	United Kingdom	51.27	-0,77	SITA	CSC		
FAE	Torshavn	Denmark	62.02	-6,82	SITA	CSC		
FAO	Faro	Portugal	37.00	-7,97	SITA	CSC		
FCO	Rome	Italy	41.80	12.25	SITA	CSC	ENR	APT
FMO	Muenster	Germany	52.12	7.68	SITA	CSC		
FNC	Funchal	Portugal	32.73	-16,7	SITA	CSC		
FOI	Foia	Portugal	37.30	-8,58	SITA	CSC		
FRA	Frankfurt	Germany	50.00	8.58	SITA	CSC	ENR	APT

FUE	Fuerteventura	Spain	28.45	-13,87	SITA	CSC		
GDN	Gdansk	Poland	54.37	18.45	SITA	CSC		
GOT	Goteborg	Sweden	57.65	12.27	SITA	CSC		
GRX	Granada	Spain	37.18	-3,77	SITA	CSC		
GRZ	Graz	Austria	46.98	15.43	SITA	CSC		
GVA	Geneva	Switzerland	46.22	6.10	SITA	CSC		
HAJ	Hannover	Germany	52.45	9.68	SITA	CSC		
HAM	Hamburg	Germany	53.62	9.98	SITA	CSC	ENR	
HEL	Helsinki	Finland	60.32	24.95	SITA	CSC		APT
IBZ	Ibiza	Spain	38.87	1.37	SITA	CSC		
IST	Istanbul	Turkey	40.97	28.82	SITA	CSC		APT
JER	Jersey	United Kingdom	49.20	-2,18	SITA	CSC		
KBP	Kiev	Ukraine	50.33	30.88	SITA	CSC		APT
KRK	Krakow	Poland	50.07	19.80	SITA	CSC		
KRS	Kristiansand	Norway	58.20	8.07	SITA	CSC		
KSC	Kosice	Slovakia	48.66	21.24	SITA	CSC		
KUO	Kuopio	Finland	63.00	27.78	SITA	CSC		
LCG	La Coruna	Spain	43.30	-8,37	SITA	CSC		
LCY	London	United Kingdom	51.50	0.03	SITA	CSC		
LEI	Almeria	Spain	36.83	-2,37	SITA	CSC		
LEJ	Leipzig	Germany	51.40	12.22	SITA	CSC		
LEQ	Lands End	United Kingdom	50.10	-5,67	SITA	CSC		
LGW	London	United Kingdom	51.15	-0,15	SITA	CSC		APT
LHR	London	United Kingdom	51.47	-0,42	SITA	CSC	ENR	APT
LIS	Lisbon	Portugal	38.77	-9,12	SITA	CSC		
LJU	Ljubljana	Slovenia	46.22	14.45	SITA	CSC		
LNZ	Linz	Austria	48.23	14.17	SITA	CSC		
LPA	Las Palmas - Gran Canaria	Spain	27.92	-15,38	SITA	CSC		
LSI	Sumburgh	United Kingdom	59.87	-1,28	SITA	CSC		
LWO	Lviv	Ukraine	49.81	23.95	SITA	CSC	ENR	
LYS	Lyon	France	45.72	5.07	SITA	CSC	ENR	
MAD	Madrid	Spain	40.50	-3,53	SITA	CSC	ENR	APT
MAH	Menorca	Spain	39.85	4.22	SITA	CSC		
MAN	Manchester	United Kingdom	53.38	-2,27	SITA	CSC	ENR	
MLA	Luqa	Malta	35.83	14.48	SITA	CSC		APT
MLH	Mulhouse	France	47.58	7.52	SITA	CSC		APT
MNT	Montejunto	Portugal	39.17	-9,05	SITA	CSC		
MOL	Molde	Norway	62.73	7.25	SITA	CSC		
MUC	Munich	Germany	48.35	11.78	SITA	CSC	ENR	APT

NCE	Nice	France	43.65	7.20	SITA	CSC		
NCL	Newcastle	United Kingdom	55.03	-1,7	SITA	CSC		
NQY	Newquay	United Kingdom	50.43	-4,98	SITA	CSC		
NUE	Nuremberg	Germany	49.50	11.05	SITA	CSC		
NWI	Norwich	United Kingdom	52.67	1.27	SITA	CSC		
ODS	Odessa	Ukraine	46.43	30.67	SITA	CSC		
OPO	Porto	Portugal	41.23	-8,68	SITA	CSC		
ORY	Paris	France	48.72	2.35	SITA	CSC		APT
OSL	Oslo	Norway	60.18	11.08	SITA	CSC	ENR	APT
OSR	Ostrava	Czech Republic	49.68	18.12	SITA	CSC		
OTP	Bucharest	Romania	44.57	26.10	SITA	CSC	ENR	
OVD	Oviedo	Spain	43.55	-6,02	SITA	CSC		
PAD	Paderborn	Germany	51.60	8.62	SITA	CSC		
PMI	Palma De Mallorca	Spain	39.53	2.72	SITA	CSC		
POZ	Poznan	Poland	52.42	16.82	SITA	CSC		
PRG	Prague	Czech Republic	50.10	14.25	SITA	CSC		
RIX	Riga	Latvia	56.92	23.97	SITA	CSC		
RLG	Rostock	Germany	53.90	12.28	SITA	CSC		
SCN	Saarbrücken	Germany	49.22	7.10	SITA	CSC		
SCQ	Santiago	Spain	42.88	-8,4	SITA	CSC		
SDL	Sundsvall	Sweden	62.08	17.38	SITA	CSC		
SIP	Simferopol	Ukraine	45.02	33.98	SITA	CSC		
SKG	Thessaloniki	Greece	40.52	22.98	SITA	CSC		
SNN	Shannon	Ireland	52.68	-8,92	SITA	CSC	ENR	
SOF	Sofia	Bulgaria	42.68	23.40	SITA	CSC		
SPC	La Palma (Santa Cruz)	Spain	28.62	-17,75	SITA	CSC		
SPU	Split	Croatia	43.53	16.28	SITA	CSC		
STN	London	United Kingdom	51.88	0.25	SITA	CSC		
STR	Stuttgart	Germany	48.68	9.22	SITA	CSC		
SVG	Stavanger	Norway	58.87	5.62	SITA	CSC		
SVQ	Sevilla	Spain	37.40	-5,9	SITA	CSC		
SXB	Strasbourg	France	48.53	7.62	SITA	CSC		APT
SXF	Berlin	Germany	52.35	13.50	SITA	CSC		
SYY	Stornoway	United Kingdom	58.20	-6,32	SITA	CSC		
TFN	Tenerife	Spain	28.47	-16,32	SITA	CSC		
TFS	Tenerife	Spain	28.05	-16,57	SITA	CSC		
TLL	Tallinn	Estonia	59.42	24.80	SITA	CSC		
TLS	Toulouse	France	43.62	1.37	SITA	CSC		APT
TRD	Trondheim	Norway	63.45	10.92	SITA	CSC		

TSR	Timisoara	Romania	45.81	21.33	SITA	CSC		
TXL	Berlin	Germany	52.55	13.28	SITA	CSC		
VAR	Varna	Bulgaria	43.23	27.82	SITA	CSC		
VBY	Visby	Sweden	57.66	18.34	SITA	CSC		
VGO	Vigo	Spain	42.22	-8,62	SITA	CSC		
VIE	Vienna	Austria	48.12	16.55	SITA	CSC	ENR	APT
VIT	Vitoria	Spain	42.87	-2,73	SITA	CSC		
VLC	Valencia	Spain	39.48	-0,48	SITA	CSC		
VNO	Vilnius	Lithuania	54.63	25.27	SITA	CSC	ENR	
WAW	Warsaw	Poland	52.17	20.93	SITA	CSC	ENR	APT
WRY	Westray	United Kingdom	59.35	-2,95	SITA	CSC		
XFW	AIRBUS Hamburg	Germany	53.53	9.82	SITA	CSC		
XRY	Jerez	Spain	36.73	-6,05	SITA	CSC		
ZAG	Zagreb	Croatia	45.73	16.07	SITA	CSC		
ZAZ	Zaragosa	Spain	41.65	-1	SITA	CSC		
ZRH	Zurich	Switzerland	47.45	8.55	SITA	CSC	ENR	APT

The following Figure reports the detail of the APT VGS deployment.

Figure 52 SITA Short term (2018) APT VGS distribution (from D09)

The following Figure reports the details of the ENR VGS distribution.

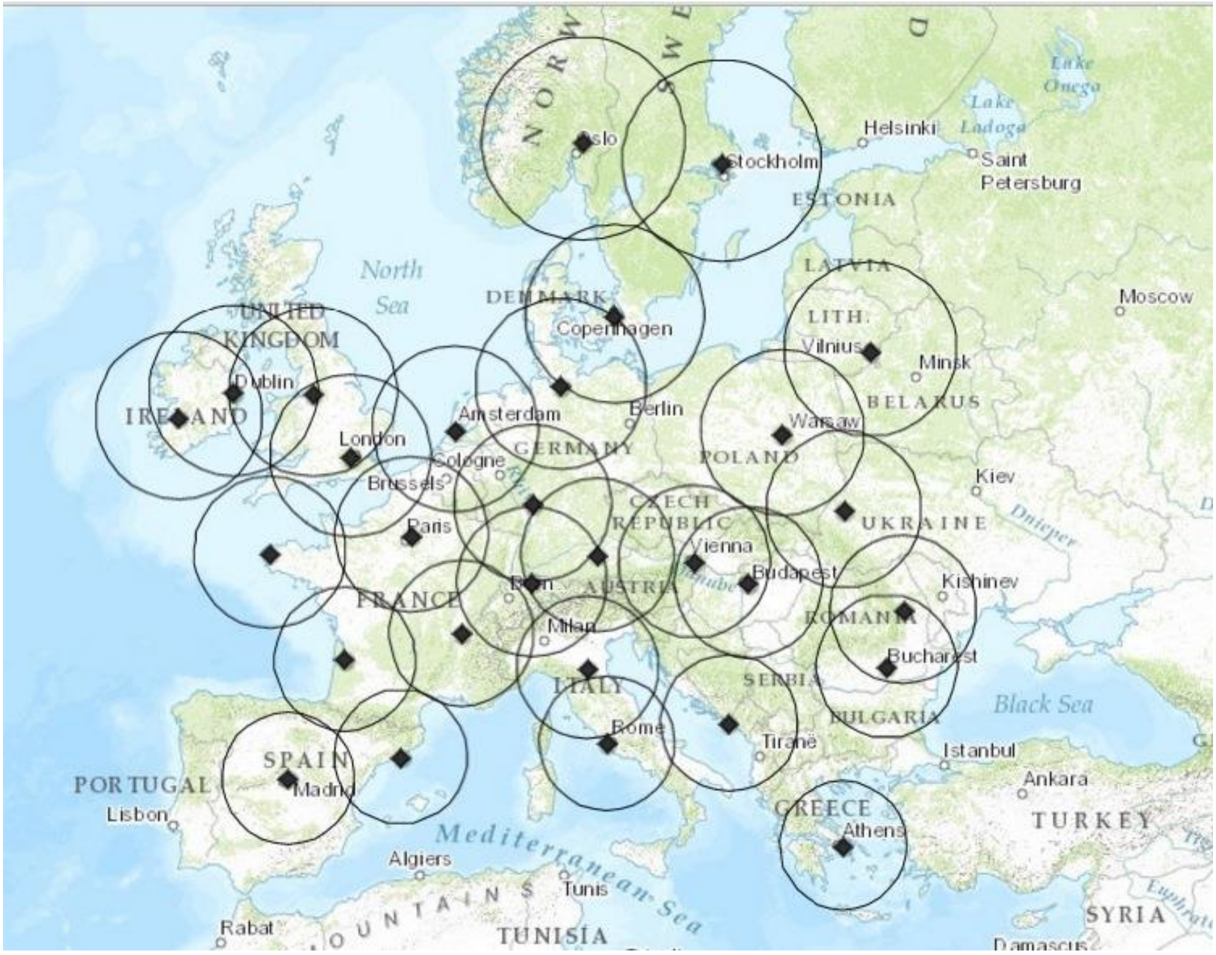


Figure 53 SITA Short term (2018) ENR VGS distribution (from D09)

G.3 MF Deployment Scenario 2020/25

Based on the information provided by ELSA partners the following MF scenario is envisaged in the medium term evolution (2020/25).

NOTE: The following scenario is only to be used for the purposes of VDL MF WA2 research within the context of ELSA. It is not a projection of traffic volumes or traffic patterns and should not be considered as such. It is not a commitment for deployments.

G.3.1 ARINC Network medium/Long term MF evolution (2020/25)

The following Table shows the medium term MF evolution envisaged by ARINC for the VDL2 network.

Table 26 ARINC MF 2020/25 - VGS Distribution and Frequency Allocation (from D09)

2020/25 MF ARINC Network - VGS Distribution and Frequency Allocation								
CODE	**SITE**	**COUNTRY**	**POSITION**		**GSIF**	**2018**		
			LAT	LON	Adv. Net	F1	F2	F5
AMS	Amsterdam	Netherlands	52.30	4.77	ARINC	CSC	APT	ENR

BER	Berlin	Germany	52.36	13.50	ARINC	CSC	APT	ENR
BES	Brest	France	48.43	-4,42	ARINC	CSC	APT	ENR
BOD	Bordeaux	France	44.82	-0,7	ARINC	CSC	APT	ENR
BRU	Brussels	Belgium	50.88	4.47	ARINC	CSC	APT	ENR
CDG	Paris	France	49.00	2.58	ARINC	CSC	APT	ENR
CGN	Cologne	Germany	50.87	7.12	ARINC	CSC	APT	ENR
DRS	Dresden	Germany	51.12	13.75	ARINC	CSC	APT	ENR
FRA	Frankfurt	Germany	50.00	8.58	ARINC	CSC	APT	ENR
GVA	Geneva	Switzerland	46.22	6.10	ARINC	CSC	APT	ENR
HAM	Hamburg	Germany	53.62	9.98	ARINC	CSC	APT	ENR
LGW	London	United Kingdom	51.15	-0,15	ARINC	CSC	APT	ENR
LHR	London	United Kingdom	51.47	-0,42	ARINC	CSC	APT	ENR
MRS	Marseille	France	43.43	5.21	ARINC	CSC	APT	ENR
MUC	Munich	Germany	48.35	11.78	ARINC	CSC	APT	ENR
NCE	Nice	France	43.65	7.20	ARINC	CSC	APT	ENR
NTE	Nantes	France	47.15	-1,6	ARINC	CSC	APT	ENR
NUE	Nuremberg	Germany	49.50	11.05	ARINC	CSC	APT	ENR
ORY	Paris	France	48.72	2.35	ARINC	CSC	APT	ENR
STR	Stuttgart	Germany	48.68	9.22	ARINC	CSC	APT	ENR
TLS	Toulouse	France	43.62	1.37	ARINC	CSC	APT	ENR
VIE	Vienna	Austria	48.12	16.55	ARINC	CSC	APT	ENR
ZRH	Zurich	Switzerland	47.45	8.55	ARINC	CSC	APT	ENR
PRG	Prague	Czech Republic	50.10	14.26	ARINC	CSC		
BLL	Billund	Denmark	55.74	9.15	ARINC	CSC		
CPH	Copenhagen	Denmark	55.61	12.65	ARINC	CSC		
LYS	Lyon	France	45.72	5.09	ARINC	CSC		
BUD	Budapest	Hungary	47.43	19.25	ARINC	CSC		
BLY	Dooncarton	Ireland	54.27	-9,83	ARINC	CSC		
BYT	Schull	Ireland	51.55	-9,54	ARINC	CSC		
DUB	Dublin	Ireland	53.42	-6,25	ARINC	CSC		
OSL	Oslo	Norway	60.19	11.10	ARINC	CSC		
BCN	Barcelona	Spain	41.29	2.07	ARINC	CSC		
MAD	Madrid	Spain	40.49	-3,56	ARINC	CSC		
ARN	Stockholm/Arlanda	Sweden	59.65	17.93	ARINC	CSC		
KSD	Karlstad	Sweden	59.44	13.33	ARINC	CSC		
OSD	Ostersund	Sweden	63.19	14.50	ARINC	CSC		
RNB	Ronneby	Sweden	56.26	15.26	ARINC	CSC		
IST	Istanbul	Turkey	40.97	28.82	ARINC	CSC		
ABZ	Aberdeen	United Kingdom	57.20	-2,2	ARINC	CSC		
BRS	Bristol	United	51.38	-2,71	ARINC	CSC		

		Kingdom						
GSY	Normanby Le Wold	United Kingdom	53.45	- 0.2931	ARINC	CSC		
LSI	Sumburgh	United Kingdom	59.87	-1,2	ARINC	CSC		
MAN	Manchester	United Kingdom	53.35	-2,27	ARINC	CSC		
NCL	Newcastle	United Kingdom	55.03	-1,7	ARINC	CSC		

The following Figures show the ARINC APT VGS and ENR VGS distribution.

Figure 54 ARINC Medium term (2020/25) APT VGS distribution (from D09)

Figure 55 ARINC Medium term (2020/25) ENR VGS distribution (from D09)

G.3.2 ENAV Network medium term MF evolution (2020/25)

The following Table shows the medium term MF evolution envisaged by ENAV for the VDL2 network.

Table 27 ENAV MF 2020/25 - VGS Distribution and Frequency Allocation (from D09)

2020/2025 MF ENAV Network - VGS Distribution and Frequency Allocation								
CODE	**SITE**	**COUNTRY**	**POSITION**		**GSIF**	**2020-25**		
			LAT	LON	Adv. Net	F1	F2	F3
AOH	Alghero	Italy	40,6298	8,29492	ARINC	CSC		ENR
BRI	Bari	Italy	41,136	16,7668	ARINC / SITA	CSC		ENR
BGY	Bergamo	Italy	45,665	9,70268	ARINC	CSC	APT	
BLQ	Bologna	Italy	44,5356	11,2994	ARINC / SITA	CSC	APT	ENR
BDS	Brindisi	Italy	40,6588	17,9405	ARINC / SITA	CSC		ENR
CAG	Cagliari	Italy	39,2555	9,05775	ARINC / SITA	CSC		ENR
QCZ	Caraffa	Italy	38,8762	16,4811	ARINC	CSC		
CTA	Catania	Italy	37,4628	15,05	ARINC / SITA	CSC		ENR
LIN	Milano Linate	Italy	45,4614	9,28057	ARINC / SITA	CSC	APT	ENR
MXP	Milano Malpensa 1	Italy	45,6208	8,73004	ARINC / SITA	CSC	APT	ENR
NAP	Napoli	Italy	40,8794	14,2855	ARINC / SITA	CSC	APT	ENR
OLB	Olbia	Italy	40,9018	9,51415	SITA	CSC		ENR
CIA	Roma Ciampino	Italy	41,8038	12,5835	ARINC	CSC		
FCO	Roma Fiumicino 1	Italy	41,8164	12,2643	ARINC / SITA	CSC	APT	ENR
FCO	Roma Fiumicino 2	Italy	41,8078	12,2492	ARINC	CSC		
TRN	Torino Caselle	Italy	45,1977	7,64577	ARINC	CSC	APT	
UST	Ustica	Italy	38,7076	13,1775	ARINC / SITA	CSC		ENR
VCE	Venezia Tessera	Italy	45,5104	12,3471	ARINC / SITA	CSC	APT	ENR
MXP	Milano Malpensa 2	Italy	45,6256	8,7395	ARINC	CSC		ENR

The following Figures show the APT VGS and ENR VGS locations.

Figure 56 ENAV Medium term (2020/25) APT VGS distribution (from D09)

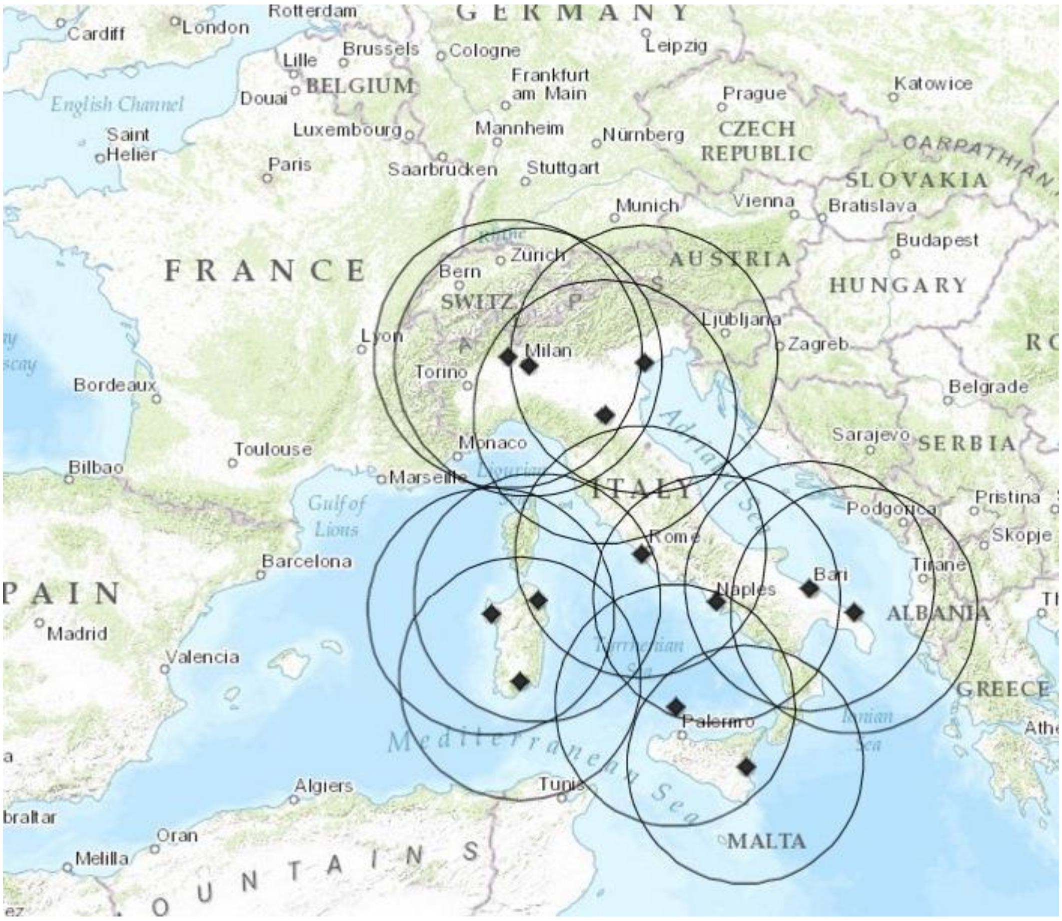


Figure 57 ENAV Medium term (2020/25) ENR VGS distribution (from D09)

G.3.3 SITA Network Medium term MF evolution (2020/25)

The following Table shows the medium term MF evolution envisaged by SITA for the VDL2 network.

Table 28 SITA MF 2020/25 - VGS Distribution and Frequency Allocation

2020/25 MF SITA Network - VGS Distribution and Frequency Allocation								
CODE	SITE	COUNTRY	POSITION		GSIF	F1	F2	F3
			LAT	LON	Adv. Net			
ABZ	Aberdeen	United Kingdom	57.20	-2,2	SITA	CSC		
ACE	Arrecife	Spain	28.95	-13,6	SITA	CSC		
AGP	Malaga	Spain	36.67	-4,47	SITA	CSC		
ALC	Alicante	Spain	38.28	-0,57	SITA	CSC		
AMS	Amsterdam	Netherlands	52.30	4.77	SITA	CSC	ENR	APT
ARN	Stockholm	Sweden	59.65	17.93	SITA	CSC	ENR	APT
ATH	Athens	Greece	37.92	23.92	SITA	CSC	ENR	APT
BCM	Bacau	Romania	46.52	26.91	SITA	CSC		
BCN	Barcelona	Spain	41.30	2.07	SITA	CSC	ENR	APT
BES	Brest	France	48.43	-4,42	SITA	CSC	ENR	APT
BHX	Birmingham	United Kingdom	52.45	-1,72	SITA	CSC		
BIO	Bilbao	Spain	43.30	-2,92	SITA	CSC		
BLL	Billund	Denmark	55.73	9.13	SITA	CSC		
BLQ	Bologna	Italy	44.52	11.28	SITA	CSC	ENR	APT
BOD	Bordeaux	France	44.82	-0,7	SITA	CSC	ENR	APT
BOJ	Burgas	Bulgaria	42.57	27.51	SITA	CSC		
BRE	Bremen	Germany	53.03	8.78	SITA	CSC		
BRR	Barra	United Kingdom	57.00	-7,5	SITA	CSC		
BRS	Bristol	United Kingdom	51.38	-2,7	SITA	CSC		
BRU	Brussels	Belgium	50.88	4.47	SITA	CSC	ENR	APT
BUD	Budapest	Hungary	47.43	19.25	SITA	CSC	ENR	
CDG	Paris	France	49.00	2.58	SITA	CSC	ENR	APT
CFU	Corfu	Greece	39.60	19.90	SITA	CSC		
CGN	Cologne	Germany	50.87	7.12	SITA	CSC		
CLJ	Cluj Napoca	Romania	46.78	23.68	SITA	CSC		
CND	Constanta	Romania	44.36	28.48	SITA	CSC		
CPH	Copenhagen	Denmark	55.62	12.63	SITA	CSC	ENR	APT
DBV	Dubrovnik	Croatia	42.55	18.27	SITA	CSC	ENR	APT
DRS	Dresden	Germany	51.12	13.75	SITA	CSC		
DTM	Dortmund	Germany	51.50	7.60	SITA	CSC		
DUB	Dublin	Ireland	53.42	-6,23	SITA	CSC	ENR	APT
DUS	Dusseldorf	Germany	51.27	6.75	SITA	CSC	ENR	APT

EDI	Edinburgh	United Kingdom	55.93	-3,35	SITA	CSC		
EFL	Argostonlion	Malta	38.12	20.50	SITA	CSC		
ERF	Erfurt	Germany	50.97	10.95	SITA	CSC		
FAB	Farnborough	United Kingdom	51.27	-0,77	SITA	CSC		
FAE	Torshavn	Denmark	62.02	-6,82	SITA	CSC		
FAO	Faro	Portugal	37.00	-7,97	SITA	CSC		
FCO	Rome	Italy	41.80	12.25	SITA	CSC	ENR	APT
FMO	Muenster	Germany	52.12	7.68	SITA	CSC		
FNC	Funchal	Portugal	32.73	-16,7	SITA	CSC		
FOI	Foia	Portugal	37.30	-8,58	SITA	CSC		
FRA	Frankfurt	Germany	50.00	8.58	SITA	CSC	ENR	APT
FUE	Fuerteventur a	Spain	28.45	-13,87	SITA	CSC		
GDN	Gdansk	Poland	54.37	18.45	SITA	CSC		
GOT	Goteborg	Sweden	57.65	12.27	SITA	CSC		
GRX	Granada	Spain	37.18	-3,77	SITA	CSC		
GRZ	Graz	Austria	46.98	15.43	SITA	CSC		
GVA	Geneva	Switzerland	46.22	6.10	SITA	CSC		
HAJ	Hannover	Germany	52.45	9.68	SITA	CSC		
HAM	Hamburg	Germany	53.62	9.98	SITA	CSC	ENR	APT
HEL	Helsinki	Finland	60.32	24.95	SITA	CSC	ENR	APT
IBZ	Ibiza	Spain	38.87	1.37	SITA	CSC		
IST	Istanbul	Turkey	40.97	28.82	SITA	CSC	ENR	APT
JER	Jersey	United Kingdom	49.20	-2,18	SITA	CSC		
KBP	Kiev	Ukraine	50.33	30.88	SITA	CSC	ENR	APT
KRK	Krakow	Poland	50.07	19.80	SITA	CSC		
KRS	Kristiansand	Norway	58.20	8.07	SITA	CSC		
KSC	Kosice	Slovakia	48.66	21.24	SITA	CSC		
KUO	Kuopio	Finland	63.00	27.78	SITA	CSC		
LCG	La Coruna	Spain	43.30	-8,37	SITA	CSC		
LCY	London	United Kingdom	51.50	0.03	SITA	CSC		
LEI	Almeria	Spain	36.83	-2,37	SITA	CSC		
LEJ	Leipzig	Germany	51.40	12.22	SITA	CSC		
LEQ	Lands End	United Kingdom	50.10	-5,67	SITA	CSC		
LGW	London	United Kingdom	51.15	-0,15	SITA	CSC	ENR	APT
LHR	London	United Kingdom	51.47	-0,42	SITA	CSC	ENR	APT
LIS	Lisbon	Portugal	38.77	-9,12	SITA	CSC		
LJU	Ljubljana	Slovenia	46.22	14.45	SITA	CSC		
LNZ	Linz	Austria	48.23	14.17	SITA	CSC		
LPA	Las Palmas -	Spain	27.92	-15,38	SITA	CSC		

	Gran Canaria								
LSI	Sumburgh	United Kingdom	59.87	-1,28	SITA	CSC		
LWO	Lviv	Ukraine	49.81	23.95	SITA	CSC	ENR	APT
LYS	Lyon	France	45.72	5.07	SITA	CSC	ENR	APT
MAD	Madrid	Spain	40.50	-3,53	SITA	CSC	ENR	APT
MAH	Menorca	Spain	39.85	4.22	SITA	CSC		
MAN	Manchester	United Kingdom	53.38	-2,27	SITA	CSC	ENR	APT
MLA	Luqa	Malta	35.83	14.48	SITA	CSC	ENR	APT
MLH	Mulhouse	France	47.58	7.52	SITA	CSC		
MNT	Montejunto	Portugal	39.17	-9,05	SITA	CSC		
MOL	Molde	Norway	62.73	7.25	SITA	CSC		
MUC	Munich	Germany	48.35	11.78	SITA	CSC	ENR	APT
NCE	Nice	France	43.65	7.20	SITA	CSC		
NCL	Newcastle	United Kingdom	55.03	-1,7	SITA	CSC		
NQY	Newquay	United Kingdom	50.43	-4,98	SITA	CSC		
NUE	Nuremberg	Germany	49.50	11.05	SITA	CSC		
NWI	Norwich	United Kingdom	52.67	1.27	SITA	CSC		
ODS	Odessa	Ukraine	46.43	30.67	SITA	CSC		
OPO	Porto	Portugal	41.23	-8,68	SITA	CSC		
ORY	Paris	France	48.72	2.35	SITA	CSC	ENR	APT
OSL	Oslo	Norway	60.18	11.08	SITA	CSC	ENR	APT
OSR	Ostrava	Czech Republic	49.68	18.12	SITA	CSC		
OTP	Bucharest	Romania	44.57	26.10	SITA	CSC	ENR	APT
OVD	Oviedo	Spain	43.55	-6,02	SITA	CSC		
PAD	Paderborn	Germany	51.60	8.62	SITA	CSC		
PMI	Palma De Mallorca	Spain	39.53	2.72	SITA	CSC		
POZ	Poznan	Poland	52.42	16.82	SITA	CSC		
PRG	Prague	Czech Republic	50.10	14.25	SITA	CSC		
RIX	Riga	Latvia	56.92	23.97	SITA	CSC		
RLG	Rostock	Germany	53.90	12.28	SITA	CSC		
SCN	Saarbrücken	Germany	49.22	7.10	SITA	CSC		
SCQ	Santiago	Spain	42.88	-8,4	SITA	CSC		
SDL	Sundsvall	Sweden	62.08	17.38	SITA	CSC		
SIP	Simferopol	Ukraine	45.02	33.98	SITA	CSC		
SKG	Thessaloniki	Greece	40.52	22.98	SITA	CSC		
SNN	Shannon	Ireland	52.68	-8,92	SITA	CSC	ENR	APT
SOF	Sofia	Bulgaria	42.68	23.40	SITA	CSC		
SPC	La Palma (Santa Cruz)	Spain	28.62	-17,75	SITA	CSC		
SPU	Split	Croatia	43.53	16.28	SITA	CSC		

STN	London	United Kingdom	51.88	0.25	SITA	CSC		
STR	Stuttgart	Germany	48.68	9.22	SITA	CSC		
SVG	Stavanger	Norway	58.87	5.62	SITA	CSC		
SVQ	Sevilla	Spain	37.40	-5,9	SITA	CSC		
SXB	Strasbourg	France	48.53	7.62	SITA	CSC	ENR	APT
SXF	Berlin	Germany	52.35	13.50	SITA	CSC		
SYY	Stornoway	United Kingdom	58.20	-6,32	SITA	CSC		
TFN	Tenerife	Spain	28.47	-16,32	SITA	CSC		
TFS	Tenerife	Spain	28.05	-16,57	SITA	CSC		
TLL	Tallinn	Estonia	59.42	24.80	SITA	CSC		
TLS	Toulouse	France	43.62	1.37	SITA	CSC	ENR	APT
TRD	Trondheim	Norway	63.45	10.92	SITA	CSC		
TSR	Timisoara	Romania	45.81	21.33	SITA	CSC		
TXL	Berlin	Germany	52.55	13.28	SITA	CSC		
VAR	Varna	Bulgaria	43.23	27.82	SITA	CSC		
VBY	Visby	Sweden	57.66	18.34	SITA	CSC		
VGO	Vigo	Spain	42.22	-8,62	SITA	CSC		
VIE	Vienna	Austria	48.12	16.55	SITA	CSC	ENR	APT
VIT	Vitoria	Spain	42.87	-2,73	SITA	CSC		
VLC	Valencia	Spain	39.48	-0,48	SITA	CSC		
VNO	Vilnius	Lithuania	54.63	25.27	SITA	CSC	ENR	APT
WAW	Warsaw	Poland	52.17	20.93	SITA	CSC	ENR	APT
WRY	Westray	United Kingdom	59.35	-2,95	SITA	CSC		
XFW	AIRBUS Hamburg	Germany	53.53	9.82	SITA	CSC		
XRY	Jerez	Spain	36.73	-6,05	SITA	CSC		
ZAG	Zagreb	Croatia	45.73	16.07	SITA	CSC		
ZAZ	Zaragosa	Spain	41.65	-1	SITA	CSC		
ZRH	Zurich	Switzerland	47.45	8.55	SITA	CSC	ENR	APT

The following Figure reports the detail of the APT VGS deployment.

Figure 58 SITA Medium term (2020-25) APT VGS distribution (from D09)

The following Figure reports the details of the ENR VGS distribution.

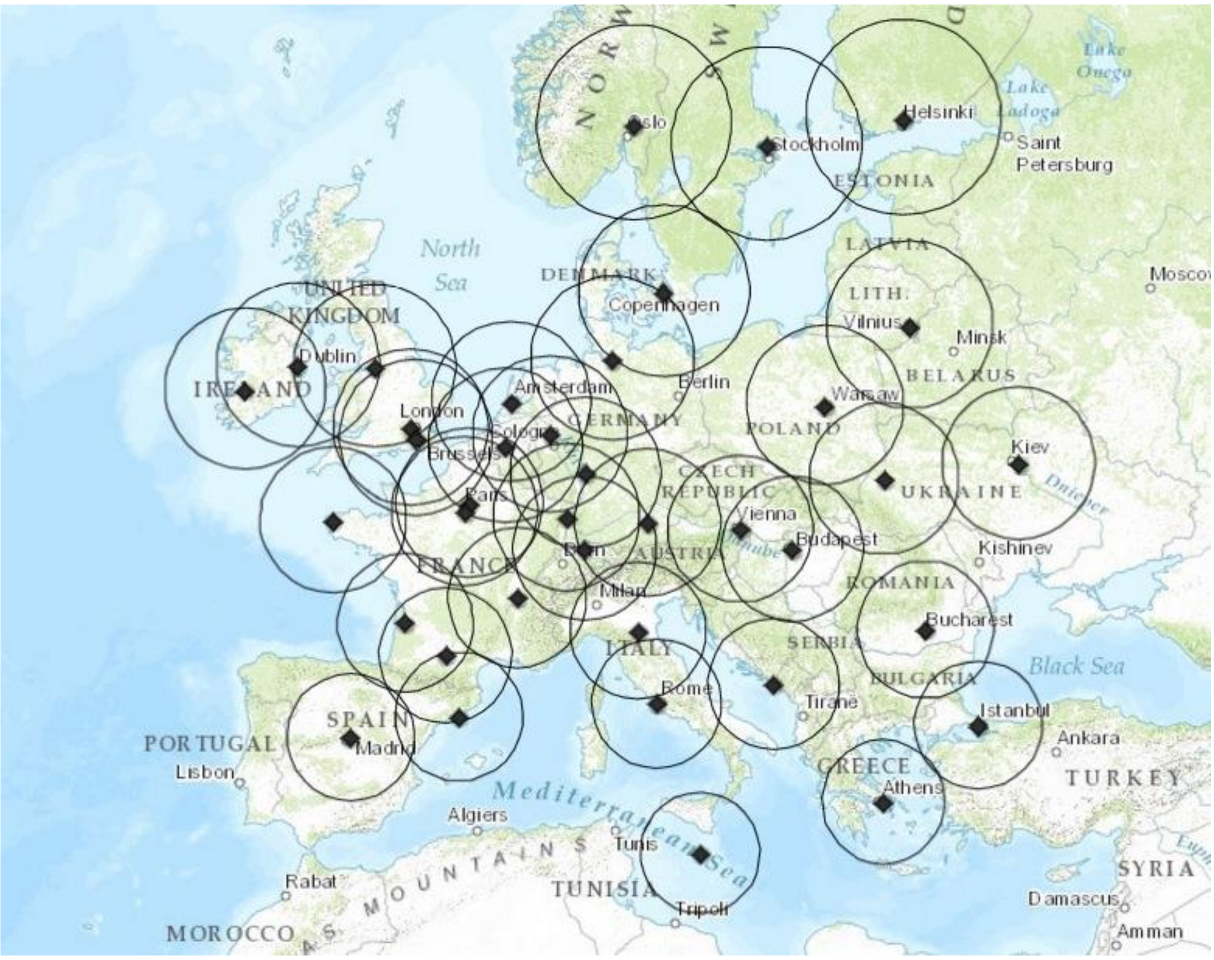


Figure 59 SITA Short term (2020/25) ENR VGS distribution (from D09)

G.4 Overall VGS distribution in Europe

The following Figure 7-42 shows all the current sites where are deployed VGS in Europe.

On ORANGE sites are present SITA VGS only

On FUCSIA sites are present SITA and ARINC VGS

On RED sites are present ARINC VGS only

On BLUE sites are presents ENAV VGS only

On CYAN sites are present SITA and ENAV VGS.

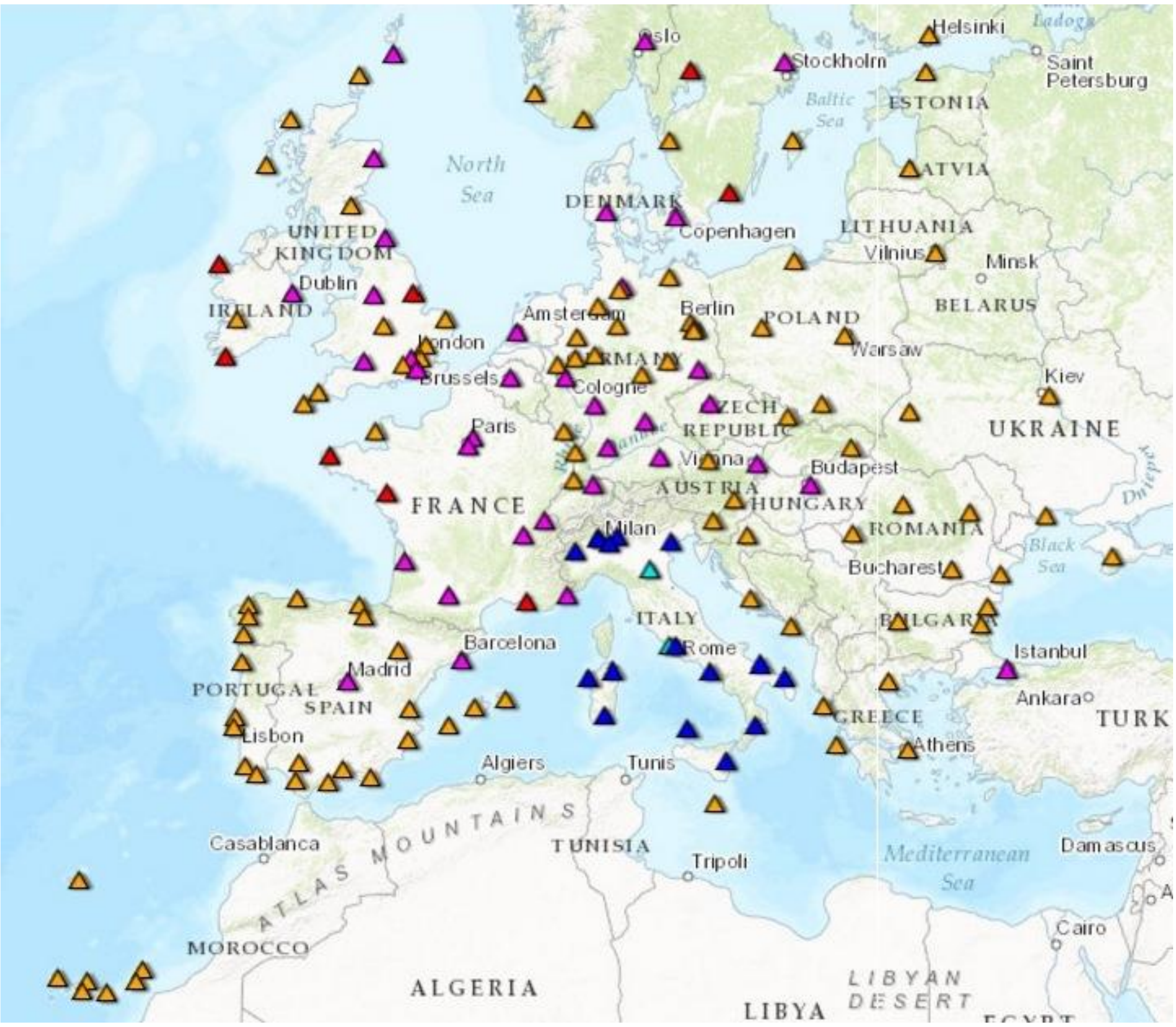


Figure 60 VGS distribution over all EU sites (from D09)

G.5 EU VDL Network Medium/Long term MF evolution (from 2025)

One of the points in the 10 point EASA action plan was as follows: “The overall locations of VGSs should be designed according to the intended service coverage.”

Based on the forecast VGS deployment plan for the short-medium term (2018-2020/25), the CSPs EU network will be deployed for the maximum capacity between 2020 and 2025; for that reason, to provide further enhancements and possible optimisations, some other means should be considered.

- **Additional VDL2 frequency allocations:** Probably this is not a valid technical proposal, as it could not be feasible; in addition SJU capacity study has shown that with 4 VDL2 channels the target performances could be maintained at least until 2025/2030, better results could be reachable with a total of 5 VDL2 channels.
- **VDL2 single network concept adoption:** In order to improve the current network some new and different concepts should be adopted and introduced in the EU VDL2 infrastructure

  3. The single network concept based on the defined Service areas
  4. Dedicated frequency allocation for a single entity
  5. Single/Dual language ground stations

The research and consolidation results provided under "Network Architecture" Section, depict a new network model (MODEL D) for the medium/long term 2025/2030.

The target model, deployed on Service areas, is based on the following assumptions:

- Single RF network (all VGSs for a Service area are managed by a single entity)
- Dedicated channel allocation (no different management entities should concur on the same channels)
- Both GSIFs presence on every channel (all users could be accepted on a single channel)

The picture below shows the different layers of coverage that need to be achieved with the VGS network.

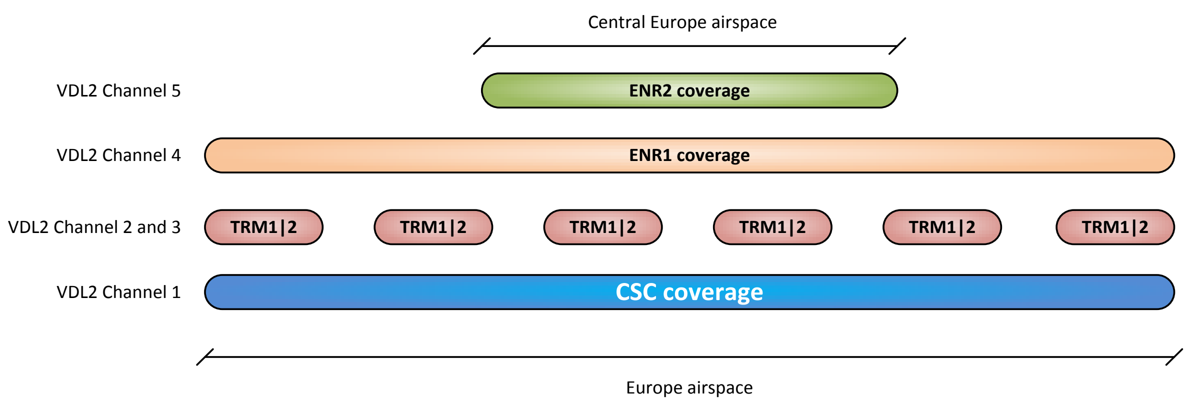


Figure 61 Long term solution VDL coverage layers (from D09)

Using this approach the next sub-chapters will provide a hypothesis for the deployment. The overall distribution of the VGSs does not consider the possible organisation in different "single networks" to address the concept of Service areas.

NOTE: The following scenario is only to be used for the purposes of VDL MF WA2 research within the context of ELSA. It is not a projection of traffic volumes or traffic patterns and should not be considered as such. It is not a commitment for deployments.

G.5.1 EU VDL Network Medium/Long term MF evolution CSC Coverage

The CSC coverage should be provided for all the VDL2 served areas, together with APT and/or ENR channels, so a radio on CSC frequency will be present on every EU VDL site.

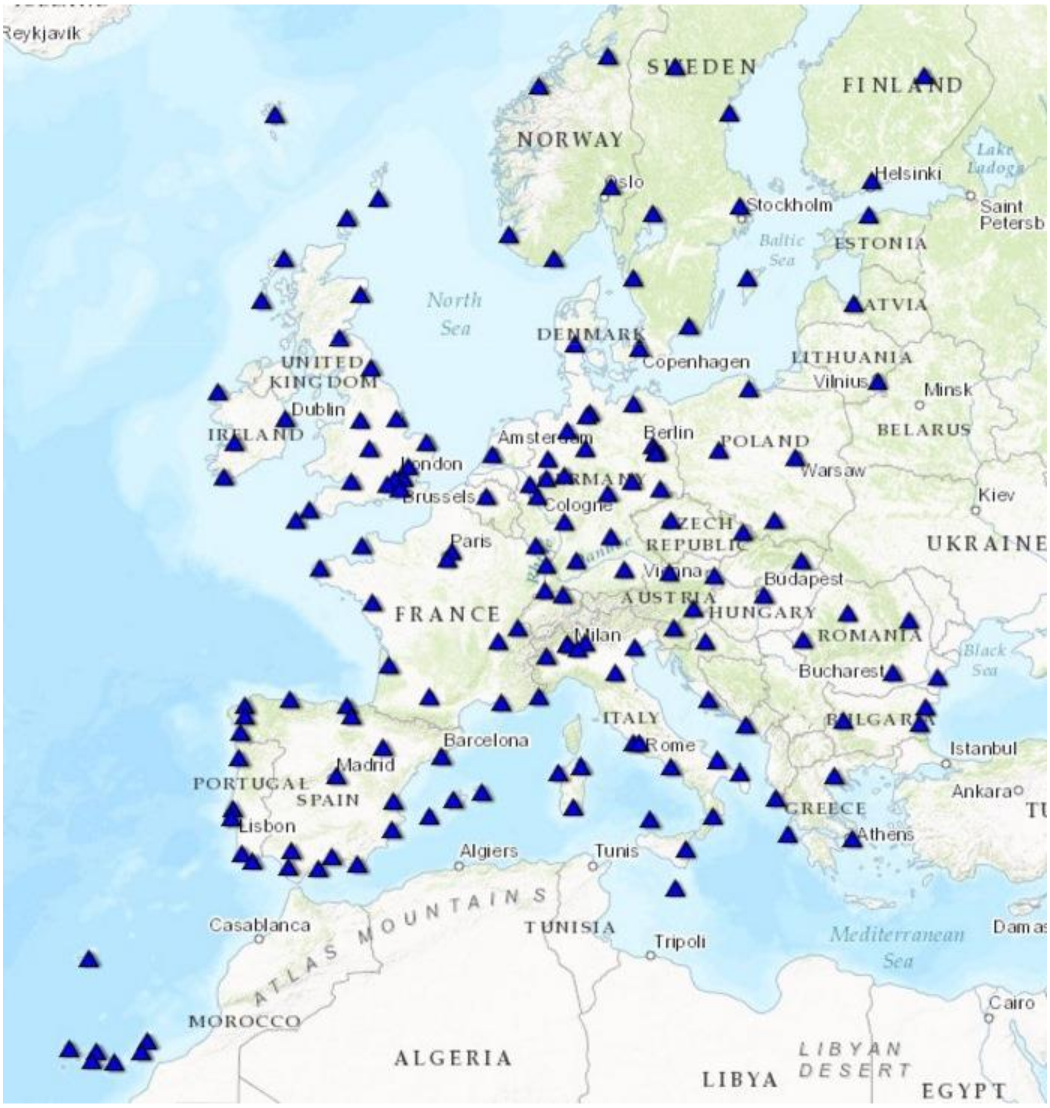


Figure 62 Long term solution CSC VDL sites (from D09)

G.5.2 EU VDL Network Medium/Long term MF evolution APT Coverage

Terminal service coverage should be provided over alternate channels on each airport, unless the APT traffic is so light to allow the use of CSC for ground operations; but taking into account a long term scenario each selected airport should be served with an alternate APT channel, and in major airports an additional APT channel will be deployed (APT1+APT2, Figure below).

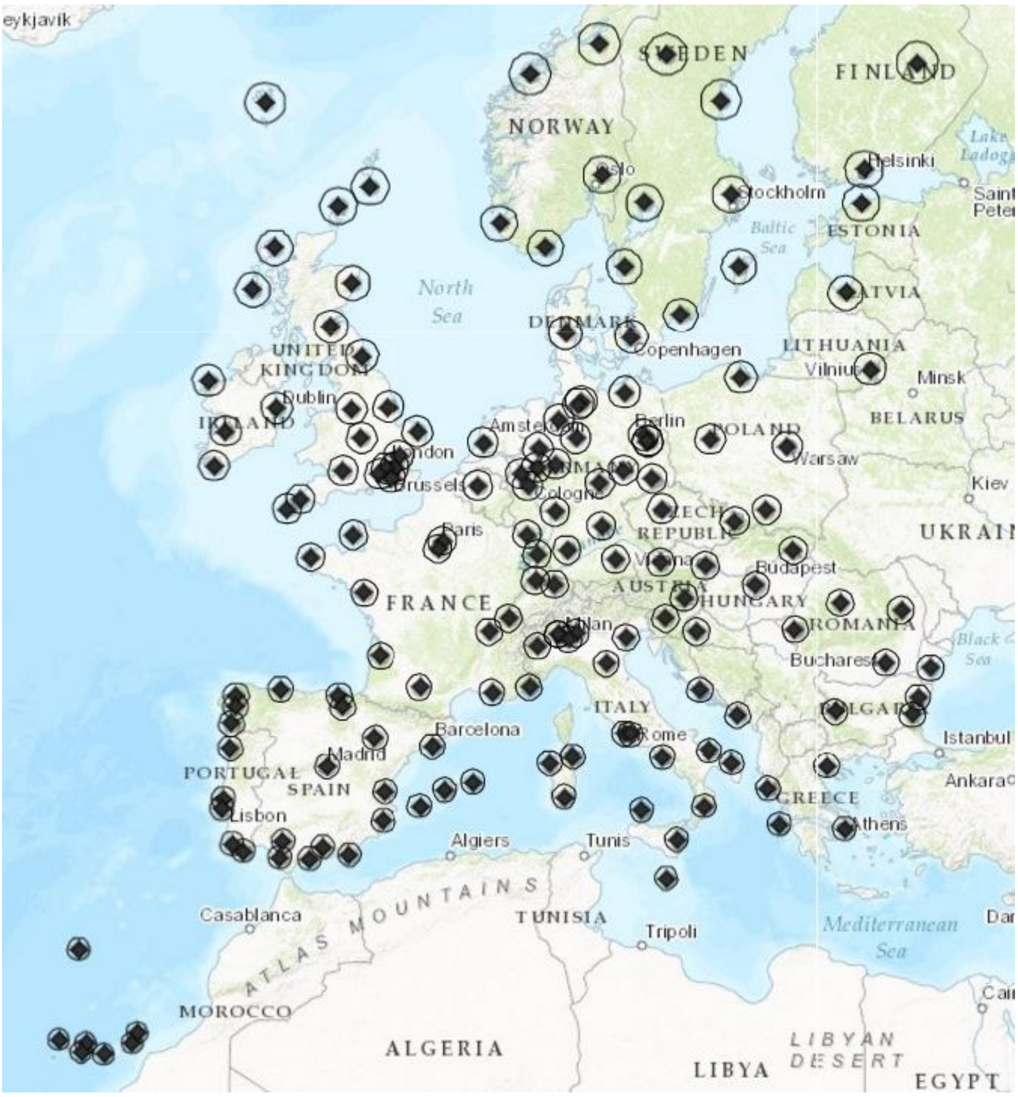


Figure 63 Long term solution APT VDL sites (from D09)

G.5.3 EU VDL Network Medium/Long term MF evolution ENR1 Coverage

A first layer for en-route service coverage should be deployed over all the EU airspace using an alternate ENR channel. The number and the position of the VGSs used should be the results of a dedicated VHF radio propagation study, taking also into account the coverage redundancy requirements.

Figure 64 Long term solution ENR1 layer coverage (from D09)

G.5.4 EU VDL Network Medium/Long term MF evolution ENR2 Coverage

A second layer for an alternate en-route service coverage, using a different ENR channel, should be deployed over the central Europe to provide the additional resources needed for the high traffic areas (Figure 65 and Figure 66).

Figure 65 Long term solution ENR2 layer coverage (from D09)

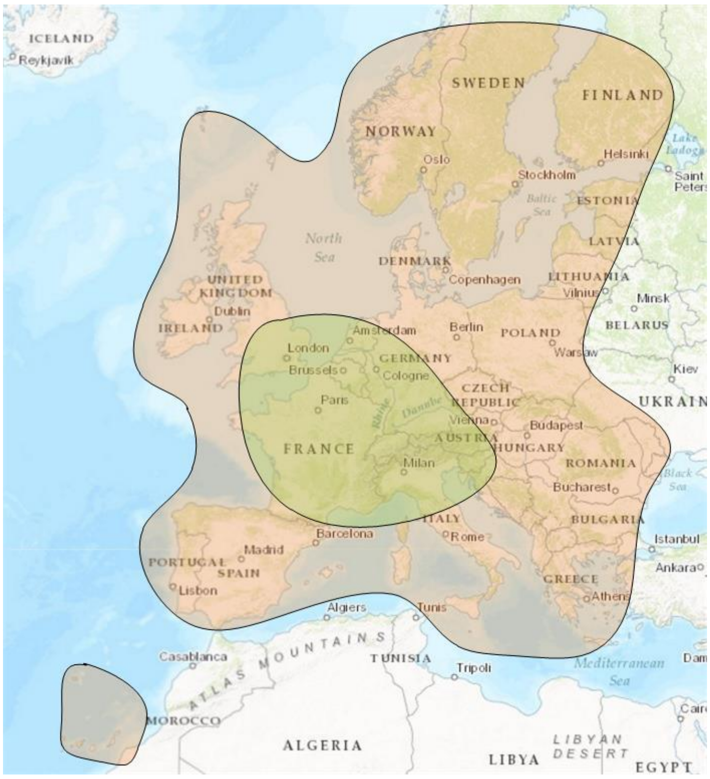


Figure 66 Long term solution ENR1 + ENR2 layers coverage (from D09)

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