Roadmap for the implementation of data link services in European Air Traffic Management (ATM):

Technology Assessment

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Document Control

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

EDITION	DATE	REASONS FOR CHANGE	SECTIONS AFFECTED
1.A	25 May 2002	Initial draft for comment covering only preliminary assessment of broadcast media.	All
1.B	10 June 2002	Draft for comment by European Commission covering only preliminary assessment of broadcast media.	All
2.A	17 July 2002	Extension to include point-to-point media and conformance with Assessment Framework.	All
2.B	15 September 2002	Adoption of format agreed at progress meeting	All
2.C	22 September 2002	Updated all broadcast sections and technology annexes.	All
2.D	30 September 2002	Inclusion of point-to-point requirements	Section 4 Annex B
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3.0	30 October 2002	Initial release to Commission	All
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4.A	24 February 2003	Updates following public consultation	All
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Executive Summary

This document is an assessment of candidate datalink technologies. It has been produced during Phase 2 of a study for the European Commission with the ultimate aim of developing a roadmap for the introduction of datalink services in European ATM.

The document is subdivided as follows:

- The main body of the report summarises the technology assessment, scenario analysis and technology selection.
- The annexes of the report describe each of the technologies considered in the study as well as the overall network architecture and cost assessment.

The following additional documents were produced during the study:

- “Executive Summary”, P167D017, version 1.0, 28th February 2003. This document contains an executive summary of the findings of the study.
- “Datalink Roadmap”, P167D2010, version 3.0, 28th February 2003. This document contains a full summary of the project including potential datalink roadmaps and community actions.
- “Application Assessment”, P167D1030 version 2.0, 30th October 2002. This document presents the results of Phase 1 which focussed on the identification, characterisation and selection of ATM applications. The document establishes initial timescales for each of the ATM applications and records stakeholder comments on the work carried out in Phase 1.
- “Non-ATS applications”, P167D1050 version 1.0, 28th February 2003. This document presents the results of a summary of requirements for non-ATS applications.
- “References”, P167D3030 version 3.0, 28th February 2003. This sets out the references used in the study.
- “Phase 2 Consultation”, P167D016 version 1.0, 28th February 2003. This document contains proceedings of the Second Stakeholder Workshop held on the 21st February 2003 and comments received on the Phase 2 deliverables.

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1 Introduction

1.1 Purpose of document

1.1.1 This document has been produced during Phase 2 of a study for the European Commission to develop a roadmap for the implementation of data link services supporting Air Traffic Management (ATM) in Europe. The work has been carried out under contract B2001/B2 – 7020B/S12.330694.

1.1.2 This study is an independent assessment of the different candidate data link technologies, with the aim of proposing the most suitable data link(s) in support of the European decision-making process.

1.1.3 The key deliverables from Phase 1 of the study are:

- *Roadmap for the implementation of data link services in European Air Traffic Management (ATM): Application Assessment*, P167D1030 – which identifies the applications to be included in the Datalink Roadmap and is supported by a high-level benefits analysis.
- *Roadmap for the implementation of data link services in European Air Traffic Management (ATM): Assessment Framework*, P167D1040 – which identifies the detailed technical requirements for the applications and identifies the methodology to be used in this report.

1.1.4 The purpose of this document is to assess the individual technologies and, in the light of the application roadmap developed in Phase 1 of the study, evaluate potential scenarios for technology deployment. A summary of the ATM applications is presented at Annex A.

1.1.5 This is the final version of the document and has been updated to reflect comments received from stakeholders during the public consultation process and the Second Workshop. These comments are summarised in [P167D016].

1.1.6 This document performs the following functions:

- Identification of retained technologies (Section 2);
- Identification of the method used in assessing individual technologies and identified scenarios (Section 3);
- Identification of requirements (Section 4);
- Assessment of individual point-to-point technologies (Section 5 and relevant annexes);
- Assessment of individual broadcast technologies (Section 6 and relevant annexes);
- Assessment of identified scenarios and selection of the most appropriate for inclusion in the roadmap (Section 7);
- A summary of the key conclusions from the technical assessment (Section 8).

1.2 References

1.2.1 A master reference list for the Datalink Roadmap project is provided in P167D3030. The references used to categorise each technology are provided in the relevant annex.

1.3 Structure of document

1.3.1 The remainder of this document consists of the following sections:

- Section 2: Identification of technologies;
- Section 3: Methodology;
- Section 4: Overall requirements;
- Section 5: Point-to-point technologies;
- Section 6: Broadcast technologies;
- Section 7: Scenario selection;
- Section 8: Conclusions;
- Section 9: Abbreviations and acronyms.

1.3.2 The document is completed by a set of annexes:

- Annex A: ATM application summary;
- Annex B: Point-to-point architectures;
- Annex C: Cost data;
- Annex D to P contain technology descriptions.

2 Identification of technologies

2.1 Purpose

2.1.1 This section identifies the technologies that have been considered as candidates in the timeframe to 2015. The technologies are presented according to the following classification:

- Current technologies which are already in operation.
- Technologies for which significant deployment decisions have been taken.
- Emerging technologies which have been subject to significant development work by the aviation community.
- Future technologies for which there are emerging development plans.

2.1.2 The current technologies along with those technologies for which significant deployment decisions have been announced are considered to be the baseline for the study.

2.2 Current technologies

2.2.1 The current technologies are those which are currently in operation or which have been mandated:

- ACARS supported by VHF, HFDL and AMSS
- Voice supported by 25kHz and 8.33 kHz
- Mode S Elementary Surveillance (mandate announced in AICs issued by Belgium, France, Luxembourg, Germany, the Netherlands and Switzerland)

2.2.2 These technologies are already deployed in Europe and in operational use. VHF datalink is the traditional basis for Airline Operational Communications (AOC) data services known as Aircraft Communications Addressing and Reporting System (ACARS). Aeronautical Mobile Satellite Service (AMSS) supports ACARS and is also used as the bearer for FANS 1/A in the Pacific and North Atlantic[1]. High Frequency Data Link (HFDL) also supports ACARS.

2.3 Technologies for which significant decisions have been taken

2.3.1 Significant deployment decisions have been made in relation to implementation of VDL2, 1090 Extended Squitter (1090 ES) and Mode S Enhanced Surveillance (Mode S ES).

2.3.2 VDL2 has been selected by some airlines, initially to support ACARS over AVLC (AOA) but also to support ATS Services using the Aeronautical Telecommunications network (ATN), in particular Lufthansa and SAS have committed to the Link2000+ programme as Pioneer Airlines. They will each equip 20 aircraft with VDL2/ATN as part of this programme.

[1] The ACARS VHF Datalink is also used to support the FANS1/A applications where there is coverage.

2.3.3 Both ARINC and SITA have significant programmes to deploy VDL2 ground stations. VDL2 is currently used to support a number of operational applications including ATIS in the United States. The FAA and Eurocontrol have selected VDL2 as the communications bearer for initial deployment of CPDLC. IATA supports these decisions.

2.3.4 The FAA[2] have recently announced decisions to deploy 1090 ES as the initial bearer for air-air and air-ground broadcast services. In the US, Universal Access Transponder (UAT) will also be deployed to support General Aviation.

2.3.5 A draft announcement from Eurocontrol, AEA, IATA and the European Commission also supports the early deployment of 1090 ES, but indicates that 1090 ES is not sufficient for all the proposed applications and that the future augmentation by VDL4 is possible[3].

2.3.6 In addition, consideration of the impact of a mandate for Mode S Enhanced Surveillance is required when assessing downlink broadcast applications. The UK, France and Germany have announced intentions to mandate Mode S Enhanced Surveillance.

2.3.1.1 In response to the Mode S Elementary Surveillance mandate, and the expected Enhanced Surveillance mandate, Airbus and Boeing are certifying Mode S transponders with Elementary Surveillance, Enhanced Surveillance, and 1090 Extended Squitter ADS-B Out functions, along with the requisite aircraft installation wiring. Initial deliveries and service bulletins for in-service aircraft will start in the first quarter of 2003, in support of fleet wide compliance by 2005.

2.3.7 CANSO recommended that ANSP with requirements for point-to-point datalink and ADS_B adopt VDL2 and 1090 ES for use during the period 2003-2012 [262.]

2.4 Emerging technologies

2.4.1 Emerging technologies are those which have yet to enter operational service but for which significant standardisation, development and trials work has been carried out. The identified technologies are:

- VDL3;
- VDL4;
- UAT;
- Gatelink.

[2] FAA Press Release APA 27-02, 1st July 2002. (See: http://www.faa.gov/asd/ads-b/press.htm)

[3] European ADS-B Data Link Recommendation, December 2002

2.4.2 It should be noted however that decisions to implement each of these technologies have also been made:

- VDL3 is being deployed by the FAA to support voice communications in 2009 and data communications by 2012.
- VDL4: Sweden [271] and Russia [272] have announced plans to implement VDL4 for ADS-B. Comm4 Solutions [273] are proposing a VDL4 network to support AOC applications.
- UAT: UAT has been selected by the FAA to support ADS-B applications for General Aviation community.
- Gatelink: BA, FedEx, Swissair and CONDOR have all supported operational trials of Gatelink.

2.4.3 In addition to these technologies, Mode S Data Link has also been standardised by ICAO. As no stakeholder has plans to implement Mode S Data Link it was not considered during the study.

2.5 Future technology

2.5.1 Future technologies are those for which there are emerging development plans but for which standardisation and demonstration is immature. The identified technologies are:

- Next Generation Satellite Service (NGSS);
- Satellite Data Link Service (SDLS);
- 3G/UMTS (CDMA Wideband);
- Boeing Connexion (Boeing CS).

2.5.2 Of these systems, 3G is considered to be a terrestrial system operating outside of the existing VHF allocation. The other systems are satellite based.

2.5.3 NGSS is used to refer to the LEO/MEO systems such as Iridium and Globalstar whose primary purpose was mass communications market but which initially offered aviation service. ICAO is currently considering none of these systems.

2.5.4 Boeing CS is a proprietary satcom system operating in Ka-band and is not intended for ATS.

2.5.5 SDLS is a long term ESA research programme aim at demonstrating improvements to the current AMSS. During the course of this study Eurocontrol have commenced work on NexSat which is a proposed L-band satcom solution which includes elements of the SDLS programme.

2.5.6 Other companies have shown interest in providing new aeronautical mobile satellite communications systems both in the existing L-band allocation and at other frequencies such as Ka- and Ku-band which do not have an aeronautical allocations. Given the embryonic nature of these systems they have not been discussed in detail.

2.6 Summary of technology support for data link requirements

2.6.1 Table 2-1 summarises the functions of the candidate technologies. Full details of these technologies are presented in the Annexes D to P.

Group	Technology	Air-Ground Datalink	Air-Air Datalink	Air-Air Broadcast	Uplink Broadcast	Downlink Broadcast	Annex
Baseline	AVPAC	✓					-
	HFDL	✓					D
	AMSS	✓					E
Significant Decisions	VDL2	✓			✓		F
	1090 ES		Note 2	✓	✓	✓	G
	Mode S ES	Note 3			✓	✓	H
Emerging	VDL3	✓					I
	VDL4	✓	✓	✓	✓	✓	J
	UAT			✓	✓	✓	K
	Gatelink	Note 4					L
Future	NGSS	✓					M
	SDLS	✓			✓		N
	3G/UMTS	✓	✓	✓	✓	✓	O
	Boeing CS				✓		P

Table 2-1: Summary data link technology characteristics

Legend:

✓: Indicates that the technology will support the indicated high level link characteristics

Notes:

1. VDL3, SDLS and 3G also support air-ground and air-air voice communications
2. 1090 MHz Extended Squitter includes a ‘crosslink’ for TCAS, which is a simple data link.
3. Mode S Enhanced Surveillance does not include the use of the Mode S Data Link.
4. Gatelink only provides air-ground communications at or near the gate.

3 Methodology

3.1 Introduction

3.1.1 The purpose of this section is to define the methods used for technology assessment and scenario identification and selection.

3.2 Technology assessment

3.2.1 The method for technology assessment includes:

- Technical assessment - consideration of the general characteristics and services supported by the media, including:
  - Capability assessment - detailed description of the technical strengths and weaknesses of the media.
  - Maturity assessment - consideration of when the media could be deployed by analysis of simulations and trials activities, standards maturity, equipment development and system deployment.
  - Complexity assessment - assessment of airborne and ground architectures including complexity of proposed solutions.
- Cost assessment: Assessment of relative cost of each technology.
- Industrial assessment: Assessment of stakeholder, avionics manufacturer and aircraft manufacturer support for the technologies.

3.2.2 Capability assessment

3.2.2.1 The capability of each technology has been assessed against the technical requirements which arose from the ATM Applications identified in Phase 1 of the study. The technical requirements are summarised in Section 4.

3.2.2.2 In particular, the following questions were considered:

- Is the technology able to meet the specified QoS?
- How many channels are required to meet the required throughput?

3.2.3 Maturity assessment

3.2.3.1 Maturity is assessed in terms of:

- System Development;
- Standards;
- Equipment;
- Deployment.

3.2.3.2 Figure 3-1 illustrates the process by which the maturity of a data link technology is assessed.

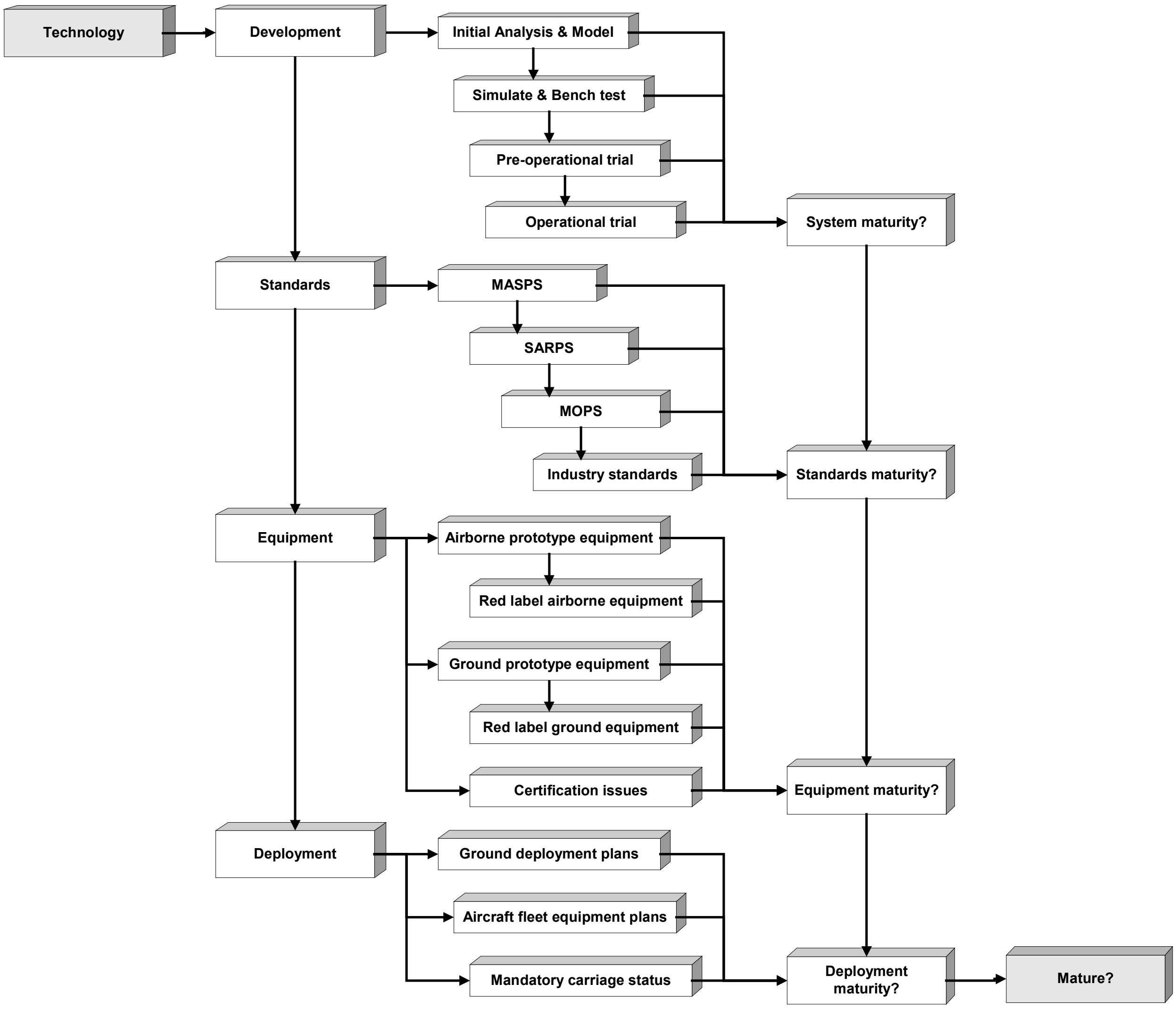

Figure 3-1: Maturity assessment method

3.2.2 Table 3-1 summarises the issues considered.

Stage	**Consideration**
System development	System development is considered to include the following steps: ▪ Initial analysis and modelling ▪ Simulations, bench testing, R&D flight trials ▪ Pre-operational trials ▪ Operational trials Each step is assigned one of the following levels: No activity, partially complete or complete. For each step the key activities and results are summarised.

Stage	Consideration
Standards development	Development of the following standards has been considered: ▪ EUROCAE/RTCA MASPS (where applicable) ▪ ICAO SARPs (and accompanying documentation, typically a Technical Manual and Implementation Manual or other Guidance material) ▪ EUROCAE/ RTCA MOPS ▪ ARINC Characteristics ▪ ETSI Standards (Only applicable to certain technologies) For each standard there are four categories of maturity: No activity, Initial Draft Available, Mature Draft Available; Validated Draft Available or Published
Equipment development	The availability of prototype, red-label and commercial equipment has been considered for both ground and airborne segments along with relevant certification issues, where: ▪ Prototype equipment is suitable for research and development trials activity ▪ Red-label equipment is suitable for pre-operational trials activity ▪ Commercial equipment is suitable for operational trials and full-scale deployment.
System deployment	System Deployment is considered in terms of plans for ground deployment, airborne deployment and associated mandates. Ground Deployment Plans ▪ Summary of European deployment plans and commitments for ANSPs and communication service providers (eg ARINC and SITA) ▪ Identification of existing infrastructure Aircraft Deployment Plans ▪ Summary of European deployment plans and commitments by airlines ▪ Identification of existing equipage Mandate Status: ▪ Has a mandate for the technology been mooted or promulgated?

Table 3-1: Maturity assessment

3.2.4 Complexity assessment

3.2.1 The assessment of airborne and ground architectures considered the complexity of the proposed solutions in terms of both airborne and ground architecture. A particular concern of the complexity assessment is the additional difficulty of co-locating diverse technologies.

3.2.2 The complexity assessment considered:

- Whether installation of the technology on the airframe is straightforward, or requires a complex integration with existing airborne equipment.
- If there are other components which are required to be fitted to the airframe in order for the technology to be used.
- If there are potential issues of incompatibility or interference with the installation of another technology onboard the airframe.

3.2.5 Cost assessment

3.2.5.1 The introduction of data link services in European ATM will cause significant costs, which will be incurred by diverse stakeholders including:

- Aircraft Operators – including additional avionics, maintenance, crew training, and training of maintenance engineers, installation costs.
- ANSPs – including communications infrastructure, control centre upgrades including potential changes to Controller Work Position (CWP), Flight Data Processor (FDP) and Radar Data Processor (RDP), controller training, training of maintenance engineers, running costs, communications charges, land rental.

3.2.5.2 The purpose of the cost assessment is to enable:

- Cost comparisons between technologies;
- The overall cost of potential scenarios to be estimated.

3.2.5.3 The cost assessment has been performed at a high level to produce 'order of magnitude' costs only. Costs have been classified as technology specific or application specific and as capital or annual:

- Technology specific costs are those which change with technology selection, for example the cost of a ground station or airborne radio.
- Application specific costs are those which are common to all technologies.
- Capital costs are one-off costs associated with the purchase of equipment.
- Annual costs are costs which are incurred in all subsequent years, for example equipment maintenance.

3.2.5.4 The following table identifies the individual cost elements considered for aircraft operators. Cost elements are included in the relevant annexes and summarised in Annex C. Costs are expressed per Air Transport aircraft and assume the retro-fit of an existing digital aircraft.

	Capital Costs	Annual Costs
Technology Specific	Avionics Radio/transponder Antenna Installation Costs (specific to radio and antenna)	Equipment maintenance
General	Avionics CMU (point-point only) CDTI (broadcast only) Installation Cost (to include upgrades to other avionics required for integration) Training maintenance engineers Training Flight Crew Project Management	Equipment maintenance

Table 3-2: Aircraft operator cost categories

3.2.5.5 The following table identifies the individual cost elements considered for ANSPs. The cost elements are listed in the relevant annexes and are summarised in Annex C. Costs are expressed per airport and per area control centre. A range of costs are considered, but an average cost is used for comparative purposes.

	Capital Costs	Annual Costs
Technology Specific	Communications Infrastructure including ground stations Installation costs Training maintenance engineers Project management	Communications Charges Equipment maintenance
General	Control system upgrades (to include FDP, RDP, CWP) Network Upgrades Controller Training	It is assumed that control centre upgrades do not incur additional running costs or require training for maintenance engineers.

Table 3-3: ANSP cost categories

3.2.5.6 In order to consider the overall costs of a specific scenario, the component costs need to be multiplied by various factors such as number of aircraft, number of ground stations, number of area control centres. This process is considered in Annex C.

3.2.6 Industrial assessment

3.2.6.1 The purpose of the industrial assessment is to assess the impact on European industry of including/ excluding the media from the Roadmap. The following issues have been considered:

- Level of support from various stakeholders such as Airlines, ANSPs and Communications Service Providers.
- The views of equipment/ technology vendors.
- The views of airframers/ integrators.

3.3 Scenario definition and selection

3.3.1 Purpose

3.3.1 A scenario is a sub-set of the identified technologies that can deliver the application roadmap - either completely, or in a way that maximises the potential benefit at a lower cost.

3.3.1.1 The following criteria have been used to select the most appropriate scenario for the inclusion in the roadmap:

- ability to deliver the application roadmap;
- overall cost;
- frequency availability;
- global interoperability;
- support for voice;
- support for non-ATC communications.

3.3.1.2 A scoring system is presented in Section 3.3.8.

3.3.2 Overall benefits

3.3.2.1 During Phase 1, a high level benefit analysis was performed which identified the potential benefits of delivering the entire application roadmap. In Section 7, benefits are in terms of the risk that the Application roadmap can not be delivered or that part so the parts of the roadmap have to be delayed.

3.3.3 Overall costs

3.3.3.1 The overall costs of each scenario are calculated by accumulating the component costs over the number of aircraft, ground stations and control centres for ECAC. The method for costing scenario is discussed in Annex C.

3.3.4 Frequency availability

3.3.4.1 A key constraint for a particular scenario is the availability of frequencies. The key concern is the availability of sufficient VHF frequencies, other concerns include:

- use of VHF Navigation Band for VDL4;
- use of DME Band for UAT;
- continued access to the AMSS frequencies (L-band);
- availability of suitable frequencies for future systems such as 3G including Ka, Ku band satellite services.

3.3.4.2 This factor includes both the availability of an aviation allocation and the spectral efficiency of the proposed media (which leads to the requirement for a specific number of channels).

3.3.5 Global interoperability

3.3.5.1 It is important that the number of technologies required on an airframe is minimised. One way of achieving this is the alignment of the datalink roadmap with other regional and global plans.

3.3.5.2 Existing plans for datalink technologies include:

- ARINC and SITA deployments of VDL2 for AOC usage;
- Eurocontrol Link2000+ plans for VDL2 for ATS;
- FAA OEP which includes deployment of VDL2 and VDL3;
- FAA plans for 1090 ES and UAT;
- Scandinavian and Russian plans for VDL4;
- Comm 4 Solutions plans to offer AOC services over VDL4.

3.3.6 Support for voice communications

3.3.6.1 ATC voice communications are required for the foreseeable future [118]. Within Europe ATC voice is supported by a mixture of 25kHz and 8.33 kHz analogue channels. 8.33 kHz is already used in core Europe with both vertical and horizontal expansion planned.

3.3.6.2 The demand for voice channels increases by 4% per year [249]. Even with the planned expansion of 8.33kHz it is still recognised that additional voice capacity may be required in the 2012-2015 timeframe, this may be alleviated by changes to the ATM paradigm which could reverse the trend for smaller and smaller sectors.

3.3.6.3 In order to support the voice requirements, it is recommended that the choice of datalink technologies includes support for voice in the period beyond 2015.

3.3.6.4 Existing satellite systems (e.g. AMSS voice) are considered sufficient for AOC and remote voice requirements. The use of AOC voice has significantly reduced in recent years.

3.3.7 Support for non-ATS communications

3.3.7.1 This study has concentrated on the requirements for datalink in support of ATM, however it is recognised that the aviation communications includes:

- AOC – Airline Operational Communications;
- AAC – Airline Administrative Communications;
- APC/IFE – Airline Passenger Correspondence/In Flight Entertainment.

3.3.7.2 The potential requirements for these types of applications are summarised in "Roadmap for the implementation of data link services in European Air Traffic Management (ATM): Non-ATS applications", P167D1050.

3.3.7.3 AOC supports the regularity of flight and are considered as safety related. AOC is traditionally supported by the same media as ATC.

3.3.7.4 Support for AOC applications is important to all airlines as it is seen as a key enabler of operational efficiency benefits.

3.3.7.5 It is recommended that the selected datalink are able to support AOC requirements.

3.3.7.6 AAC and APC/IFE are non-safety related. AAC relates to typically narrow band applications that support the airline operation but a are not concerned with the safety and regularity of flight, for example baggage handling. APC/IFE however has significantly different characteristics to ATS communications and typically requires a broadband solution.

3.3.7.7 It is not recommended that the chosen technologies are able to support APC/IFE, but it is recommended that a combined datalink be considered for future datalink.

3.3.8 Scoring

3.3.1 Each criterion has a weighting which indicates its importance. Each scenario is awarded a score for each category based on the criteria summarised in Table 3-4.

Score	Rationale	
Criteria: Ability to deliver the application roadmap		**Weighting:** 6
5	All benefits realised	
4	One step of the application road map cannot be delivered.	
3	Two steps of the application road map cannot be delivered.	
2	Risk that application roadmap is not delivered.	
1	Significant risk that application roadmap is not delivered.	
Criteria: Overall Cost		**Weighting:** 4
5	Lowest Value to 10% greater that lowest value	
4	10% to 20% greater than lowest value	
3	20% to 30% greater than lowest value	
2	30 to 40% greater than lowest value	
1	40% or more greater than lowest value	
Criteria: Frequency Availability		**Weighting:** 4
5	All required frequencies available	
4	Use of allocated band, but simple frequency planning required to free up frequencies from current users	
3	Use of allocated band, but complex frequency planning required to free up frequencies from current users	
2	WRC co-ordination required to re-assign aviation frequencies	
1	Frequencies required for which no aviation allocation currently exists	
Criteria: Global interoperability		**Weighting:** 2
5	Compatible with all global solutions	
4	Compatible with most global solutions	
3	Compatible with some global solutions	
2	Compatible with some regional solutions	
1	Incompatible with non-European solutions	
Criteria: Support for voice		**Weighting:** 2
5	Selected technologies include support for predicted voice requirements	
4	Selected technologies include support for predicted voice requirements in specific regions	
3	Selected technologies include support for emergency voice communications	
2	Selected technologies include support for emergency voice communications in specific regions.	
1	Selected technologies include no support for voice	
Criteria: Support for non-ATC communications		**Weighting:** 2
5	Sufficient bandwidth for all aeronautical communications	
4	Sufficient bandwidth for all aeronautical communications in specific airspace	
3	AOC support included	
2	AOC support included in specific airspace	
1	No Non ATC support included	

Table 3-4: Scenario selection criteria

4 Overall requirements

4.1 Purpose

4.1.1 The purpose of this section is to identify the overall requirements which need to be met by the selected technologies.

4.1.2 In Section 4.2 the Application Roadmap is presented in terms of the ATM applications required in each homogenous zone. The requirements are then developed separately for point-to-point and broadcast technologies[4].

4.1.3 In each case the discussion is presented in two parts:

- Architecture – In this section the potential architectures for providing the services are considered. This enables the overall requirement to be portioned across the overall architecture.
- Requirements – In this section the requirements are expressed as a progression of technical requirements for each Homogenous Zone, including the overall capacity required.

4.2 The application roadmap

4.2.1 The Phase 1 analysis results in the delivery of capacity in five steps:

- Step 1: Early a/g ATM applications. This step requires the deployment of an initial air-ground datalink.
- Step 2: ATM applications related to downlink of air-derived data. This step could be achieved by the use of additional datalink applications or the deployment of a downlink broadcast media.
- Step 3: Introduction of spacing. This step requires the deployment of ADS-B within the aircraft including processing and display capabilities. It could be supported by the use of TIS-B.
- Step 4: Extension of a/g ATM applications. This step involves additional use of the air-ground datalink; it could involve the deployment of a new technology or just additional frequencies.
- Step 5: Introduction of:
  - a) separation and self-separation which would require a dual-link ADS-B solution; and/or
  - b) conflict free trajectory negotiation which would require an enhanced air-ground datalink

4.2.2 These steps are defined in full in the separate “Datalink Roadmap” document.

[4] Air-Air Point-to-point is considered within the section on broadcast requirements.

4.2.3 The following tables define the ATM Applications within each potential step for each homogenous zone.

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b– Strategic controller/pilot messages	DLIC DCL ACL ACM	CPDLC-0
	APP4a – Provision of terminal (automatic terminal information service, meteorological report) and runaway information	D-ATIS METAR	D-FIS-0
2	APP13a – Fusion of current terminal/surface radar with other surveillance means	ADS-B	ADS-B-S0
3	APP12a – Surface enhanced visual acquisition APP12b – Runway and final approach occupancy awareness APP13b – ATC surveillance using ADS-B at airports APP12c – Enhanced IMC airport surface operations	ADS-B	ADS-B-S1
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	D-FIS-0
5a	APP13c – A-SMGCS Routing	ACL	CPDLC-3

Table 4-1: Application roadmap for surface operations

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b – Strategic controller/pilot messages	DLIC ACL ACM DCL DSC	CPDLC-0
	APP4a – Provision of terminal (automatic terminal information service, meteorological report) and runaway information	D-ATIS METAR	D-FIS-0
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c – Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
	APP1d – Fusion of current radar and ADS-B surveillance in terminal and en-route airspace	ADS-B	ADS-B-A-0
3	APP3b – Enhanced Visual Acquisition in terminal airspace APP3c – Enhanced Visual Approaches	ADS-B TIS-B	ADS-B-A0
	APP9a – Airborne Spacing in en-route and terminal airspace APP9c – Final Approach Spacing APP9d – Departure Spacing	ADS-B TIS-B	ADS-B-A1
4	APP2a – Pilot Preferences Datalink	PPD	ADAP-0
	APP2c – Support for increased automation APP7a – Provision of information on route availability	FLIPCY DYNAV	CPDLC-2
	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	ADAP-0
5a	APP1e – ATC Surveillance using ADS-B in terminal and en-route airspace	ADS-B	ADS-B-A2
	APP10b – Airborne Separation in en-route and terminal airspace APP10c – Final Approach Separation	ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC FLIPCY FLIPINT	CPDLC-3

Table 4-2: Application roadmap for terminal operations

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b – Strategic controller/pilot messages	DLIC ACL ACM DSC	CPDLC-0
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c – Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
	APP1d – Fusion of current radar and ADS-B surveillance in terminal and en-route airspace	ADS-B	ADS-B-A0
3	APP3d – Traffic Situational Awareness in core and transitional airspace	ADS-B TIS-B	ADS-B-A0 TIS-B-0
	APP9a – Airborne Spacing in en-route and terminal airspace APP9b – Crossing and passing in en-route airspace	ADS-B TIS-B	ADS-B-A1 TIS-B-1
4	APP2a – Pilot Preferences Datalink	PPD	ADAP-0
	APP2c– Support for increased automation APP7a – Provision of information on route availability	FLIPCY FLIPINT DYNAV	CPDLC-2
	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	ADAP-0
5a	APP1e – ATC Surveillance using ADS-B in terminal and en-route airspace APP10b – Airborne Separation in en-route and terminal airspace	ADS-B TIS-B	ADS-B-A2 TIS-B-2
		ACL	CPDLC-1
	APP11a – Cluster Control in ATC Managed Airspace	ADS-B	ADS-B-A2
		ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC FLIPCY FLIPINT	CPDLC-3

Table 4-3: Application roadmap for en-route and transition applications

Step	ATM Applications	D/L Services	Requirements Category
1	APP14b – ATS in oceanic and remote regions	ADS-C	ADS-C-1
2	APP14a – Basic Surveillance Infrastructure via ADS-B in remote regions	ATSAW ADS-B	ADS-B-A2
3	APP3a – EVA in remote and oceanic airspace	ADS-B	ADS-B-A0
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	ADAP-0
	APP7a – Provision of information on route availability	DYNAV	CPDLC-2
5a	APP10a – Airborne Separation in Oceanic and Remote Airspace	ADS-B TIS-B	ADS-B-A2 TIS-B-2
		ACL	CPDLC-1
	APP11b – Autonomous Operations in FFAS	ADS-B	ADS-B-A2
		PPDLC	AADE-0
		ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC FLIPCY FLIPINT	CPDLC-3

Table 4-4: Application roadmap for oceanic and remote operations

4.3 Point-to-point architectures

4.3.1 Reference architecture

4.3.1.1 The proposed 'reference' architecture for point-to-point transactions is illustrated Figure 4-1.

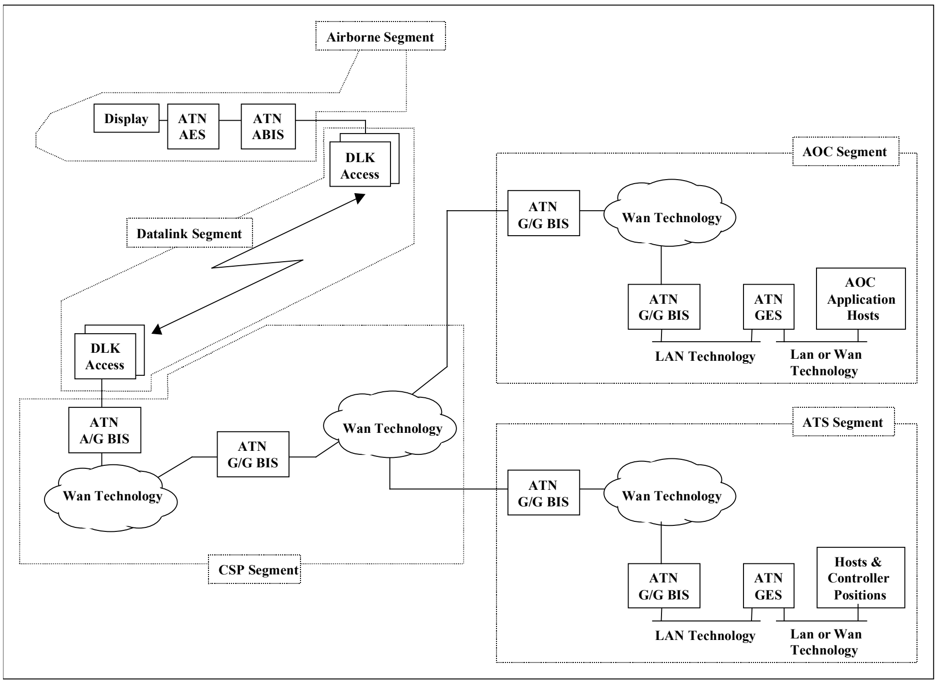

Figure 4-1: Point-to-point reference architecture

4.3.1.2 The proposed architecture focuses on the network equipment used during an end-to-end communication between an airborne end user (application or pilot) and a ground end user. In particular, the architecture definition mainly focuses on the type and number of network components involved in the end-to-end communication.

4.3.1.3 Four different segments have been identified in the proposed reference architecture:

- the airborne segment;
- the Communication Service Provider (CSP) segment;
- the Air Traffic Service (ATS) segment;
- the Aeronautical Operational Control (AOC) segment.

These four segments represent the end-to-end communication architecture within which the datalink segment operates. Annex B provides a description of these segments, as well as topology justifications.

4.3.1.4 The proposed architecture is valid in whichever airspace is considered. In all cases, the CSP must ensure its role of interface between the datalink access point and the AOC or ATS segment, for whatever region the aircraft is flying in, and for whichever datalink access point location.

4.3.2 End-to-end architecture impact

4.3.2.1 Each of the previous segments has an influence on the end-to-end performances of the application that uses the communication segment. So this impact has to be precisely dimensioned for all the technical characteristics identified, and for each segment.

4.3.2.2 The following table presents technical characteristics of the various segment of the point-to-point architecture, apart from the datalink segment (See details in Annex B, section B.3).

Point-to-point technical characteristics	Airborne Segment	CSP Segment	ATS Segment	AOC Segment
Transit delay	2.5 sec	1.5 sec	2.5 sec	2.5 sec
Priority	Buffering mechanism	Priority handling at each node	Priority handling at each node	Priority handling at each node
Integrity	Very high due to the limited size of the segment	10^{-8}	10^{-8}	10^{-8}
Availability	Very high, guaranteed with redundancy and high layers mechanisms	Very high, guaranteed with redundancy and high layers mechanisms	Very high, guaranteed with redundancy and high layers mechanisms	Very high, guaranteed with redundancy and high layers mechanisms
Exchange Size	No constraint	No constraint	No constraint	No constraint
Message Frequency	No constraint	Further detailed study need	Further detailed study need	Further detailed study need
Throughput	No constraint	Further detailed study need	Further detailed study need	Further detailed study need

Table 4-5: Point-to-point architecture segments characteristics

4.4 Point-to-point requirements

4.4.1 Data requirements

4.4.1.1 The point-to-point applications bear different types of information, from simple clearances between aircrew and controller, to the selective transmission of large information (weather, flight plan, and trajectories).

4.4.1.2 Due to the large scope of data exchanged, each application sends messages of a variety of sizes. The two key parameters of the data requirements impacted by the different homogeneous zones are the exchanges size and the total number of exchanges in a given zone. The different QoS parameters related to the ATM applications namely time, integrity and availability are only slightly influenced by the distribution in homogeneous zones.

4.4.2 Evaluation scenarios

4.4.2.1 Introduction

4.4.2.1.1 The following sections define point-to-point requirements for the following homogeneous zones:

- Airport surface
- Terminal airspace
- En-Route and transition
- Remote and Oceanic

4.4.2.2 Airport surface

4.4.2.2.1 Table 4-6 summarises the ATM Applications implemented on the airport surface during each step of the ATM Application Roadmap which require air-ground point-to-point communications services.

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b – Strategic controller/pilot messages	DLIC ACL ACM DCL	CPDLC-0
	APP4a – Provision of terminal (automatic terminal information service, meteorological report) and runaway information	D-ATIS METAR	D-FIS-0
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	D-FIS-0
5	APP13c – A-SMGCS Routing	ACL	CPDLC-3
Note: APP4a could be provided as an uplink broadcast service.			

Table 4-6: Airport Surface: Point-to-point applications

4.4.2.2.2 Point-to-point datalink transactions on the airport surface are very limited; significant information can be exchanged at the gate during flight planning procedures.

4.4.2.2 The following table identifies the category requirement in terms of exchange size, and number of exchanges per flight for each of the above applications. The average data exchange rate has been calculated assuming that duration of this phase of flight is **10 minutes.**

ATM Applications	D/L Services	Requirements Category	Size per exchange (bytes)	Exchanges per flight	Average Data Exchange Rate (bytes per second)
Step 1					
APP2b	DLIC	CPDLC-0	200	2	0.7
APP4a	D-ATIS	D-FIS-0	250	2	0.8
	METAR	D-FIS-0	250	2	0.8
Step 4					
APP4b	NOTAM	D-FIS-0	350	2	1.2
	SNOWTAM	D-FIS-0	400	2	1.3
	D-SIGMET	D-FIS-0	300	2	1.0
	D-RVR	D-FIS-0	100	2	0.3
Step 5a					
APP13c	Enhanced ACL	CPDLC-3	50	1	0.4

Table 4-7: Airport Surface: Data exchange requirements

4.4.2 The estimated number of aircraft to be supported in the service volume for surface applications is shown in the table below.

Year	2000	2005	2010	2015	2020
Aircraft	300	300	300	300	300

Table 4-8: Airport Surface: Number of mobiles

Note: Figures in above table are derived from a figure of 300 mobiles taken from reference [154]. No traffic growth is assumed for airport density.

4.4.2.2.1 The capacity requirements for Airport Surface are the following:

	Step 1	Step 2	Step 3	Step 4	Step 5
Bits per second per flight					
CPDLC-0	5.3	5.3	5.3	5.3	5.3
CPDLC-3	0.0	0.0	0.0	0.0	3.3
D-FIS-0	15.7	15.7	15.7	44.0	44.0
Total	**21.0**	**21.0**	**21.0**	**49.3**	**52.7**

Table 4-9: Airport Surface: Application capacity requirements

4.4.2.3 Terminal airspace

4.4.2.3.1 Table 4-10 summarises the ATM Applications implemented in terminal airspace during each step of the ATM Application Roadmap which require air-ground point-to-point communications services.

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b – Strategic controller/pilot messages	DLIC ACL ACM DCL DSC	CPDLC-0
	APP4a – Provision of terminal (automatic terminal information service, meteorological report) and runaway information	D-ATIS METAR	D-FIS-0
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c – Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
4	APP2a – Pilot Preferences Datalink	PPD	ADAP-0
	APP2c – Support for increased automation APP7a – Provision of information on route availability	FLIPCY DYNAV	CPDLC-2
	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	D-FIS-0
5a	APP1e – ATC Surveillance using ADS-B in terminal and en-route airspace APP10b – Airborne Separation in en-route and terminal airspace APP10c – Final Approach Separation	ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC FLIPCY FLIPINT	CPDLC-3

Table 4-10: Terminal Airspace: Point-to-point applications

4.4.2.3.2 The following table identifies the requirement category, size, exchange size per flight for each of the above applications. The average data exchange rate is calculated on the basis of an average duration for this phase of flight of **40 minutes.**

ATM Applications	D/L Services	Requirements Category	Size per exchange (bytes)	Exchanges per flight	Average Data Exchange Rate (bytes per second)
Step 1					
APP2b	DLIC	CPDLC-0	200	*10*	0.8
	ACL	CPDLC-0	100	*25*	1.0
	ACM	CPDLC-0	150	*10*	0.6
	DSC	CPDLC-0	200	*5*	0.4
APP4a	D-ATIS	D-FIS-0	250	*4*	0.4
	METAR	D-FIS-0	250	*4*	0.4
Step 2					
APP1a	CAP	ADAP-1	25	*420*	4.4
APP1b					
APP1c	SAP	ADAP-1	40	*600*	10.0
Step 4					
APP2a	PPD	ADAP-0	35	*50*	0.7
APP2c	FLIPCY	CPDLC-2	600	*5*	1.3
APP7a	DYNAV	CPDLC-2	550	*5*	1.1
APP4b	NOTAM	D-FIS-0	350	*2*	0.3
	SNOWTAM	D-FIS-0	400	*1*	0.2
	D-SIGMET	D-FIS-0	300	*2*	0.3
	D-RVR	D-FIS-0	100	*4*	0.2
Step 5					
APP1e	ACL	CPDLC-1	50	*10*	0.2
APP10c	ACL	CPDLC-1	50	*10*	0.2
APP2d	COTRAC	CPDLC-3	800	*5*	1.7
	FLIPINT	CPDLC-2	520	*20*	4.3
	FLIPCY	CPDLC-2	600	*5*	1.3

Table 4-11: Terminal Airspace: Point-to-point application requirements

4.4.2.3.3 The estimated number of aircraft to be supported in the service volume for surface applications is shown in the table below.

Year	2000	2005	2010	2015	2020
Aircraft	111	149	188	226	265

Table 4-12: Terminal Airspace: Aircraft numbers

Note: Figures in above table are derived from figures from the Core Europe 2005 and 2015 scenarios taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

4.4.2.3.4 The following table defines the capacity requirements for terminal airspace.

	Step 1	Step 2	Step 3	Step 4	Step 5
Bits per second per flight					
CPDLC-0	23.3	23.3	23.3	23.3	23.3
CPDLC-1	0.0	0.0	0.0	0.0	3.3
CPDLC-2	0.0	0.0	0.0	19.2	19.2
CPDLC-3	0.0	0.0	0.0	0.0	58.0
ADAP-0	0.0	0.0	0.0	5.8	5.8
ADAP-1	0.0	115.0	115.0	115.0	115.0
D-FIS-0	7.8	7.8	7.8	13.7	13.7
Total	**31.1**	**146.1**	**146.1**	**177.0**	**238.3**

Table 4-13: Terminal Airspace: Application capacity requirements

4.4.2.4 En-route and transition

4.4.2.4.1 Table 4-14 summarises the ATM applications implemented for en-route operations during each step of the ATM application roadmap which require air-ground point-to-point communications services.

Step	ATM Applications	D/L Services	Requirements Category
1	APP2b – Strategic controller/pilot messages	DLIC ACL ACM DCL DSC	CPDLC-0
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c – Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
4	APP2a – Pilot Preferences Datalink	PPD	ADAP-0
	APP2c– Support for increased automation APP7a – Provision of information on route availability	FLIPCY DYNAV	CPDLC-2
	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	ADAP-0
5a	APP10b – Airborne Separation in en-route and terminal airspace	ACL	CPDLC-1
	APP11a – Cluster Control in ATC Managed Airspace	ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC FLIPCY FLIPINT	CPDLC-3

Table 4-14: En-route and transition: Point-to-point applications

4.4.2.2 The following table identifies the requirement category, size, exchange size per flight for each of the above applications. The average data exchange rate is calculated on the basis that the average duration of this phase of flight is **40 minutes**.

ATM Applications	D/L Services	Requirements Category	Size per exchange (bytes)	Exchanges per flight	Average Data Exchange Rate (bytes per second)
Step 1					
APP2b	DLIC	CPDLC-0	200	7	0.6
	ACL	CPDLC-0	100	30	1.3
	ACM	CPDLC-0	150	5	0.3
	DSC	CPDLC-0	200	5	0.4
Step 2					
APP1a	CAP	ADAP-1	25	210	2.2
APP1b					
APP1c	SAP	ADAP-1	40	210	3.5
Step 4					
APP2a	PPD	ADAP-0	35	15	0.2
APP2c	FLIPCY	CPDLC-2	600	3	0.8
APP7a	DYNAV	CPDLC-2	550	5	1.1
APP4b	NOTAM	D-FIS-0	350	1	0.1
	SNOWTAM	D-FIS-0	400	1	0.2
	D-SIGMET	D-FIS-0	300	1	0.1
Step 5					
APP10b	ACL	CPDLC-1	50	0	0.0
APP11a	ACL	CPDLC-1	50	0	0.0
APP2d	COTRAC	CPDLC-3	800	5	1.7
	FLIPINT	CPDLC-3	520	20	4.3
	FLIPCY	CPDLC-3	600	3	0.8

Table 4-15: En-route and transition: Point-to-point application requirements

4.4.2.4.1 The number of aircraft to be supported in the service volume for en-route and transition area applications is shown in the table below.

Year	2000	2005	2010	2015	2020
Aircraft	515	622	729	836	943

Table 4-16: Aircraft numbers for en-route and transition area applications

Note: Figures in above table are derived from figures from the Core Europe 2005 and 2015 scenarios taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

4.4.2.4.2 The following table defines the capacity requirements for en-route and transition airspace.

	Step 1	Step 2	Step 3	Step 4	Step 5
Bits per second per flight					
CPDLC-0	20.5	20.5	20.5	20.5	20.5
CPDLC-1	0.0	0.0	0.0	0.0	1.7
CPDLC-2	0.0	0.0	0.0	15.2	15.2
CPDLC-3	0.0	0.0	0.0	0.0	54.0
ADAP-0	0.0	0.0	0.0	1.8	1.8
ADAP-1	0.0	45.5	45.5	45.5	45.5
D-FIS-0	0.0	0.0	0.0	3.5	3.5
Total	**20.5**	**66.0**	**66.0**	**86.4**	**142.1**

Table 4-17: En-route and transition: Capacity requirements

4.4.2.5 Remote and oceanic

4.4.2.5.1 Table 4-18 summarises the ATM applications requiring point-to-point communications used in remote and oceanic airspace for each step in the applications roadmap.

Step	ATM Applications	D/L Services	Requirements Category
1	APP14b – ATS in oceanic and remote regions	ADS-C	ADS-C-1
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	D-FIS-0
	APP7a – Provision of information on route availability	DYNAV	CPDLC-2
5a	APP10a – Airborne Separation in Oceanic and Remote Airspace	ACL	CPDLC-1
	APP11b – Autonomous Operations in FFAS	ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC	CPDLC-3

Table 4-18: Remote and oceanic: Point-to-point services

4.4.2.5.2 The following table identifies the requirement category, size, exchange size per flight for each of the above applications. The average data exchange rate is calculated assuming a phase of flight duration of **120 minutes**.

ATM Applications	D/L Services	Requirements Category	Size per exchange (bytes)	Exchanges per flight	Average Data Exchange Rate (bytes per second)
Step 1					
APP14b	ADS-C	ADS-C-1	60	120	1.00
Step 4					
APP4b	NOTAM	D-FIS-0	350	1	0.05
	SNOWTAM	D-FIS-0	400	1	0.06
	D-SIGMET	D-FIS-0	300	1	0.04
APP7a	DYNAV	CPDLC-2	550	1	0.08
Step 5					
APP10a	ACL	CPDLC-1	50	10	0.07
APP11b	ACL	CPDLC-1	50	10	0.07
APP2d	COTRAC	CPDLC-3	800	5	0.56
	FLIPCY	CPDLC-3	520	20	1.44
	FLIPINT	CPDLC-3	600	3	0.25

Table 4-19: Remote and oceanic: Point-to-point application requirements

4.4.2.5.3 The size presented in the previous table is directly related to the size of the total ATM transaction at the D/L Service level. The number of exchanges per flight is the number of ATM transaction inferred from a reference flight over ECAC.

4.4.2.5.4 The number of aircraft to be supported in the service volume for remote and oceanic area applications is shown in the table below.

Year	2000	2005	2010	2015	2020
Aircraft	90	90	90	90	90

Table 4-20: Remote and Oceanic: Aircraft Numbers

Note: Figures in above table are derived from figures from the Low Density scenario taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

4.4.2.5.5 The main requirement for Remote and Oceanic ATM applications is range rather than capacity. Indeed, in these zones, the traffic density is very low and the procedures are specially adapted to reduce the ATM data exchanges. On the other hand, there are inherent limits to the deployment of the ground infrastructure.

4.4.2.5.6 The following table defines the capacity requirements for remote and oceanic applications.

	Step 1	Step 2	Step 3	Step 4	Step 5
Bits per second per flight					
CPDLC-1	0.0	0.0	0.0	0.0	1.1
CPDLC-2	0.0	0.0	0.0	0.6	0.6
CPDLC-3	0.0	0.0	0.0	0.0	18.0
ADS-C-1	8.0	8.0	8.0	8.0	8.0
D-FIS-0	0.0	0.0	0.0	1.2	1.2
Total	**8.0**	**8.0**	**8.0**	**9.8**	**28.9**

Table 4-21: Remote and oceanic: Capacity requirements

4.5 Broadcast architectures

4.5.1 Airborne architecture

4.5.1.1 The potential airborne architectures are:

- Tx Only – The aircraft is able to construct and transmit ADS-B reports. This is a simple architecture in that no cockpit display is provided. The transponder is integrated with various sources for the information required to create the messages, these include the Flight Management System, Air Data Computer, Mode Change Panel and Navigation Sources.
- Tx/Rx – The aircraft is able to transmit and receive messages. In addition to the TX only architecture, integration with a flight display is required, this may be a Cockpit Display of Traffic Information (CDTI) or integrated in to more general purpose display. An ASAS processor would also be required to process received data and implement any application specific processing.

4.5.1.2 The exact architecture is dependant upon the airframe in question.

4.5.2 Ground architecture

4.5.2.1 On the ground, broadcast technologies would form part of the surveillance architecture. In Europe, this would include the use of ARTAS and SSR Mode S.

4.5.2.2 The potential ground architectures are:

- Tx Only – Ground segment is able to transmit information to aircraft (FIS-B and TIS-B). TIS-B could be used to uplink the entire air-picture to receive only aircraft, or to uplink information to equipped aircraft of proximate aircraft which are not equipped (‘gap-filler’).
- Rx Only – Ground segment is able to receive aircraft information supporting enhanced surveillance like services.
- Tx/Rx – Ground segment is able to support air-ground and ground-air services.

4.5.3 Potential architectures

4.5.3.1 The purpose of this section is to define a set of inter-network architectures to support broadcast services. Table 4-22summarises the potential combinations of airborne and ground architectures.

#	Airborne Function	Ground Function	Supported Topologies	Notes
1	TX	RX	Air-ground broadcast	This architecture enables air-ground broadcast services only and could be used as a replacement for Mode S Enhanced Surveillance. It does not however support any airborne applications and assumes that the ground infrastructure is provided first.
2	TX/RX	None	Air-air broadcast Air-air point-to-point	All air-air applications are enabled. This architecture is applicable to oceanic airspace.
3	TX/RX	TX	Air-air broadcast Air-air point-to-point Ground-air broadcast	All air-air applications are enabled. TIS-B can be used to support the 'gap-filling' FIS-B is enabled. Enhanced surveillance applications are not enabled.
4	TX/RX	RX	Air-air broadcast Air-air point-to-point Air-ground broadcast	All air-air applications are enabled. Enhanced surveillance applications are enabled. TIS-B can not be supported.
5	TX/RX	TX/RX	Air-air broadcast Air-air point-to-point Ground-air broadcast Air-ground broadcast	All applications are enabled.

Table 4-22: Potential broadcast architectures

4.5.3.2 The applicability of the proposed architectures is dependant upon the airspace considered:

- Airport Surface. Both CDTI and CWP applications are envisaged, TIS-B is not considered due to latency requirements, which are much tighter for surface applications.
- Terminal - Both CDTI and CWP applications are envisaged, TIS-B can be used to support certain applications. SSR surveillance is likely.
- En-route – mixture of Mode S and ADS-B providing enhanced surveillance

- Remote – surveillance could be based on ADS-B only.
- Oceanic – no surveillance infrastructure is provided. ADS-C is supported by beyond line of sight media. ADS-B is used to support CDTI operations.

4.5.2 Only architecture 5 has the flexibility to deliver the full application set including the required safety and capacity benefits. and is assumed for steps 3 and 5a. Architecture 1 is used in the first step of the roadmap which is only concerned with downlink of airborne parameters.

4.6 Broadcast requirements

4.6.1 Data requirements

4.6.1.1 The ADS-B applications consist of the regular broadcast and/or reception of predefined reports. The ADS-B MASPS does not define the contents of ADS-B messages. Instead, each media uses a different set of messages that can be assembled to form an ADS-B report.

4.6.1.2 Fundamentally, ADS-B reports contain:

- current position and velocity information;
- status Information;
- short Term Intent Information;
- long Term Intent Information.

4.6.1.3 The ADS-B reports defined in the MASPS are:

- SV - State Vector, contains (see MASPS section 3.4.3):
  - identification (participant address and address qualifier);
  - time of applicability;
  - geometric position (altitude not required on ground);
  - horizontal velocity (not required on ground);
  - ground speed and heading (not required when airborne);
  - barometric altitude (not required on ground);
  - vertical rate (not required on ground);
  - navigation integrity category;
  - report mode.
- MS - Mode Status (see MASPS section 3.4.4):
  - identification (participant address and address qualifier);
  - time of applicability;
  - ADS-B version number;
  - call sign;
  - emitter category;
  - A/V length and width codes;

    - status;
    - capability class codes;
    - operational mode parameters;
    - service quality parameters;
    - data reference;
- SC – status change report (see MASPS section 3.4.6):
    - identification (participant address and address qualifier);
    - time of applicability;
    - TCAS status;
    - service quality;
    - TC report management;
- ARV - Air Reference Velocity (see MASPS section 3.4.7):
    - identification (participant address and address qualifier);
    - time of applicability;
    - airspeed;
    - heading.
- TS - Target State Report (see MASPS section 3.4.8):
    - identification (participant address and address qualifier);
    - time of applicability;
    - horizontal short term intent;
    - vertical short term intent.
- TC+0, TC+n - Trajectory Change Report (see MASPS section 3.4.4):
    - identification (participant address and address qualifier);
    - time of applicability;
    - TC report sequence number and version;
    - time to go;
    - horizontal TC report information;
    - vertical TC report information.

4.6.1.4 The SC, ARV, TS and TC reports are on-condition reports. They are only broadcast when the data in them changes.

4.6.1.5 The information content of an ADS-B report is required to have a certain accuracy and integrity. Assuming that sufficient bits are allowed for each parameter these requirements place constraints on the data sources and not the delivery media.

4.6.2 Evaluation scenarios

4.6.2.1 Introduction

4.6.2.1.1 The following sections define the evolution of requirements for the following Homogenous Zones:

- Airport surface
- Terminal airspace
- En-Route and transition
- Remote and oceanic

4.6.2.2 Airport surface

4.6.2.2.1 The following ATM applications requiring broadcast services are considered for use on the airport surface:

Step	ATM Applications	D/L Services	Requirements Category
1	APP4a – Provision of terminal (automatic terminal information service, metrological report) and runway information	D-ATIS METAR	D-FIS-0
2	APP13a – Fusion of current terminal/surface radar with other surveillance means	ADS-B	ADS-B-S0
3	APP12a – Surface enhanced visual acquisition APP12b – Runway and final approach occupancy awareness APP13b – ATC surveillance using ADS-B at airports APP12c – Enhanced IMC airport surface operations	ADS-B	ADS-B-S1
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	D-FIS-0
Note 1: APP4a can also be provided as a point-to-point service			

Table 4-23: Airport Surface: Broadcast applications

4.6.2.2.2 The following table identifies the topology, requirements category, range, acquisition, EUP (as derived from the ADS-B MASPS [141])_and time frame for each of the above applications.

ATM Application	Topology	D/L Service	Requirements category	Range	Acquisition	EUP
Step 1						
APP4a	Ground-air broadcast	D-ATIS	D-FIS-0	5nm	10 s	5 s
		METAR	D-FIS-0	5nm	10 s	5 s
Step 2						
APP13a	Air-Ground Broadcast	ADS-B	ADS-B-S0	10 nm	<10 s	1 s
Step 3						
APP12a	Air-Air Broadcast	ADS-B	ADS-B-S0	5 nm	<10 s	1 s
APP12b	Air-Air Broadcast	ADS-B	ADS-B-S0	5 nm	<10 s	1 s
APP12c	Air-Air-Broadcast	ADS-B	ADS-B-S1	5 nm	<10 s	1 s
APP13b	Air-Ground Broadcast	ADS-B	ADS-B-S1	10 nm	<10 s	1 s
Step 4						
APP4b	Ground-Air Broadcast	NOTAM	D-FIS-0	5 nm	10 s	5 s
		SNOWTAM	D-FIS-0	5 nm	10 s	5 s
		D-SIGMET	D-FIS-0	5 nm	10 s	5 s
		D-RVR	D-FIS-0	5 nm	10 s	5 s
Note 1. APP4a can also be provided as a point-to-point application						

Table 4-24: Airport Surface: Broadcast application requirements

4.6.2.2.3 The number of aircraft to be supported in the service volume for surface applications is shown in the table below.

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Aircraft	300	300	300	300	300

Table 4-25: Airport Surface: Number of mobiles

Note: Figures in above table are derived from a figure of 300 mobiles taken from reference [154]. No traffic growth is assumed for airport density.

4.6.2.3 Terminal airspace

4.6.2.3.1 The following ATM applications requiring broadcast media are considered for use in terminal airspace:

Step	ATM Applications	D/L Services	Requirements Category
1	APP4a – Provision of terminal (automatic terminal information service, metrological report) and runway information	D-ATIS METAR	D-FIS-0
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
	APP1d – Fusion of current radar and ADS-B surveillance in terminal and en-route airspace	ADS-B	ADS-B-A-0
3	APP3b – Enhanced Visual Acquisition in terminal airspace APP3c – Enhanced Visual Approaches	ADS-B TIS-B	ADS-B-A0
	APP9a – Airborne Spacing in en-route and terminal airspace APP9c – Final Approach Spacing APP9d – Departure Spacing	ADS-B TIS-B	ADS-B-A1
4	APP4b– Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET D-RVR	D-FIS-0
5a	APP1e – ATC Surveillance using ADS-B in terminal and en-route airspace APP10b – Airborne Separation in en-route and terminal airspace APP10c – Final Approach Separation	ADS-B	ADS-B-A2

Table 4-26: Terminal Airspace: Broadcast applications

4.6.2.3.2 The following table identifies the topology, requirements category, range, acquisition, EUP (as derived from the ADS-B MASPS [141]) and time frame for each of the above applications.

ATM Application	Topology	D/L Service	Requirements category	Range	Acquisition	EUP
Step 1						
APP4a	Ground-Air Broadcast	D-ATIS	D-FIS-0	60 nm	10 s	5 s
		METAR	D-FIS-0	60 nm	10 s	5 s
Step 2						
APP1a	Air-Ground Broadcast	CAP	ADAP-1	60 nm	10 s	5 s
APP1b	Air-Ground Broadcast	CAP	ADAP-1	60 nm	10 s	5 s
APP1c	Air-Ground Broadcast	SAP	ADAP-1	60 nm	10 s	5 s
APP1d	Air-Ground Broadcast	ADS-B	ADS-B-A0	60 nm	10 s	5 s
Step 3						
APP3b	Air-Air Broadcast	ADS-B	ADS-B-A0	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-0	60 nm	10 s	5 s
APP3c	Air-Air Broadcast	ADS-B	ADS-B-A0	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-0	60 nm	10 s	5 s
APP9a	Air-Air Broadcast	ADS-B	ADS-B-A1	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-1	60 nm	10 s	5 s
APP9c	Air-Air Broadcast	ADS-B	ADS-B-A1	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-1	60 nm	10 s	5 s
APP9d	Air-Air Broadcast	ADS-B	ADS-B-A1	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-1	60 nm	10 s	5 s
Step 4						
APP2a	Air-Ground Broadcast	PPD	ADAP-0	60 nm	10 s	5 s
APP4b	Ground-Air Broadcast	NOTAM	D-FIS-0	60 nm	10 s	5 s
		SNOWTAM	D-FIS-0	60 nm	10 s	5 s
		D-SIGMET	D-FIS-0	60 nm	10 s	5 s
		D-RVR	D-FIS-0	60 nm	10 s	5 s
Step 5						
APP1e	Air-Ground Broadcast	ADS-B	ADS-B-A2	60 nm	10 s	5 s
APP10b	Air-Air Broadcast	ADS-B	ADS-B-A2	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-2	60 nm	10 s	5 s
APP10c	Air-Air Broadcast	ADS-B	ADS-B-A2	40 nm	10 s	5 s
	Ground-Air Broadcast	TIS-B	TIS-B-2	60 nm	10 s	5 s

Table 4-27: Terminal Airspace: Broadcast application requirements

4.6.2.3.3 The number of aircraft to be supported in the service volume for terminal area applications is shown in the table below.

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Aircraft	111	149	188	226	265

Table 4-28: Aircraft numbers for terminal area applications

Note: Figures in above table are derived from figures from the Core Europe 2005 and 2015 scenarios taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

4.6.2.3.2 En-route and transition

4.6.2.3.1 The following ATM applications requiring broadcast media are considered for use in en-route and transition areas.

Step	**ATM Applications**	**D/L Services**	**Requirements Category**
2	APP1a – Limited Enhanced Surveillance in terminal and en-route airspace APP1b – Enhanced Surveillance in terminal and en-route airspace providing a wider range of DAPS APP1c – Enhanced Surveillance accuracy for automation tools in terminal and en-route airspace	CAP SAP	ADAP-1
	APP1d – Fusion of current radar and ADS-B surveillance in terminal and en-route airspace	ADS-B	ADS-B-A0
3	APP3d – Traffic Situational Awareness in core and transitional airspace	ADS-B TIS-B	ADS-B-A0 TIS-B-0
	APP9a – Airborne Spacing in en-route and terminal airspace APP9b – Crossing and passing in en-route airspace	ADS-B TIS-B	ADS-B-A1 TIS-B-1
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	ADAP-0
5a	APP1e – ATC Surveillance using ADS-B in terminal and en-route airspace APP10b – Airborne Separation in en-route and terminal airspace	ADS-B TIS-B	ADS-B-A2 TIS-B-2
		ACL	CPDLC-1
	APP11a – Cluster Control in ATC Managed Airspace	ADS-B	ADS-B-A2
		ACL	CPDLC-1
5b	APP2d – Trajectory Negotiation	COTRAC	CPDLC-3

Table 4-29: En-route and transition: Broadcast applications

4.6.2.3.2 The following table identifies the topology, requirements category, range, acquisition, EUP (as derived from the ADS-B MASPS [141]) and time frame for each of the above applications.

ATM Application	Topology	D/L Services	Requirements category	Range	Acquisition	EUP
Step 2						
APP1a	Air-Ground Broadcast	CAP	ADAP-1	150 nm	24 s	12 s
APP1b	Air-Ground Broadcast	CAP	ADAP-1	150 nm	24 s	12 s
APP1c	Air-Ground Broadcast	SAP	ADAP-1	150 nm	24 s	12 s
APP1d	Air-Ground Broadcast	ADS-B	ADS-B-A0	150 nm	24 s	12 s
Step 3						
APP3d	Air-Air Broadcast	ADS-B	ADS-B-A0	40 nm	24 s	12 s
	Ground-Air Broadcast	TIS-B	TIS-B-0	150 nm	24 s	12 s
APP9a	Air-Air Broadcast	ADS-B	ADS-B-A1	40 nm	24 s	12 s
	Ground-Air Broadcast	TIS-B	TIS-B-1	150 nm	24 s	12 s
APP9b	Air-Air Broadcast	ADS-B	ADS-B-A1	40 nm	24 s	12 s
	Ground-Air Broadcast	TIS-B	TIS-B-1	150 nm	24 s	12 s
Step 4						
APP2a	Air-Ground Broadcast	PPD	ADAP-0	150 nm	24 s	12 s
APP4b	Ground-Air Broadcast	NOTAM	D-FIS-0	150 nm	24 s	12 s
		SNOTAM	D-FIS-0	150 nm	24 s	12 s
		SIGMET	D-FIS-0	150 nm	24 s	12 s
Step 5						
APP1e	Air-Ground Broadcast	ADS-B	ADS-B-A2	150 nm	24 s	12 s
APP10b	Air-Air Broadcast	ADS-B	ADS-B-A2	40 nm	24 s	12 s
	Ground-Air Broadcast	TIS-B	TIS-B-2	150 nm	24 s	12 s
APP11a	Air-Air Broadcast	ADS-B	ADS-B-A2	40 nm	24 s	12 s

Table 4-30: En-route and transition: Broadcast application requirements

4.6.2.3.3 The number of aircraft to be supported in the service volume for en-route and transition area applications is shown in the table below.

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Aircraft	515	622	729	836	943

Table 4-31: En-route and transition: Aircraft Numbers

Note: Figures in above table are derived from figures from the Core Europe 2005 and 2015 scenarios taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

4.6.2.3.3 Remote and oceanic

4.6.2.3.1 The following ATM applications requiring broadcast media are considered for remote and oceanic areas.

Step	ATM Applications	D/L Services	Requirements Category
2	APP14a – Basic Surveillance Infrastructure via ADS-B in remote regions	ATSAW ADS-B	ADS-B-A2
3	APP3a – EVA in remote and oceanic airspace	ADS-B	ADS-B-A0
4	APP4b – Provision of full range of uplink information services	NOTAM SNOWTAM D-SIGMET	ADAP-0
5a	APP10a – Airborne Separation in Oceanic and Remote Airspace	ADS-B TIS-B	ADS-B-A2 TIS-B-2
	APP11b – Autonomous Operations in FFAS	ADS-B	ADS-B-A2
		PPDLC	AADE-0

Table 4-32: Remote and oceanic: Broadcast applications

4.6.2.3.2 The following table identifies the topology, requirements category, range, acquisition, EUP (as derived from the ADS-B MASPS [141]) and time frame for each of the above applications.

ATM Application	Topology	D/L Service	Requirements category	Range	Acquisition	EUP
Step 2						
APP14a	Air-Ground Broadcast	ADS-B	ADS-B-A2	200 nm	24 s	12 s
Step 3						
APP3a	Air-Air Broadcast	ADS-B	ADS-B-A0	120 nm	24 s	12 s
Step 4						
APP4b	Ground-Air Broadcast	NOTAM	D-FIS-0	150 nm	24 s	12 s
		SNOTAM	D-FIS-0	150 nm	24 s	12 s
		SIGMET	D-FIS-0	150 nm	24 s	12 s
Step 5						
APP10a	Air-Air Broadcast	ADS-B	ADS-B-A2	40 nm	24 s	12 s
	Ground-Air Broadcast	TIS-B	TIS-B-2	200 nm	24 s	12 s
APP11b	Air-Air Broadcast	ADS-B	ADS-B-A2	120 nm	24 s	12 s
Note 1: Ground-air broadcast supports remote radar-like services and is not applicable to oceanic control.						

Table 4-33: Remote and oceanic: Broadcast application requirements

4.6.2.3.3 The number of aircraft to be supported in the service volume for remote and oceanic area applications is shown in the table below.

Year	2000	2005	2010	2015	2020
Aircraft	90	90	90	90	90

Table 4-34: Remote and oceanic: Aircraft Numbers area applications

Note: Figures in above table are derived from figures from the Low Density scenario taken from Appendix H of reference [15] with extrapolation to 2000, 2010 and 2020.

5 Point-to-point technologies

5.1 Purpose

5.1.1 This section assesses the relative merits of the candidate point-to-point technologies. Full descriptions of these technologies are provided in the annexes.

5.2 Technology assessment

5.2.1 Capability assessment

5.2.1.1 This section provides a comparison of the technologies ability to meet the key requirements of the application roadmap.

5.2.1.2 Table 5-1 summarises the key performance characteristics for the current and near term media.

Data Link Technologies	HFDL	AMSS	VDL2	VDL3	VDL4
Time Delay	50 to 250 sec	5 to 20 sec	Uplink: between 0.4s to 1.4s Downlink: between 0.4s and 0.9s	1.5 sec in uplink 3.5 sec in downlink	1 sec[5]
Priority	2 levels	15 levels[6]	No	Up to 4 levels	4 levels
Integrity	10^{-4}	10^{-6}	10^{-6}	10^{-5}	10^{-5}
Availability	99.9%	99.9%	99.9935%	99.9%	99.9%
Channel Rate[7]	1800 bps	10.5 kbps[8]	31.5 kbps	31.5 kbps	19.2 kbps
Capacity and Coverage	130 aircraft for 3 stations	Near global coverage	130 NM for a station	200 NM for a station	200 NM for a station

Table 5-1: Performance characteristics for point-to-point media

5.2.1.3 Of the various VDLs, it is noted that VDL2 does not support priority mechanisms and further it use of CDMA means that it can not support deterministic QoS. This means that VDL2 should not be considered for time critical applications. It is however noted that if sufficient channels are available to keep the channel loading low, typically less than 20%, then VDL2 could support these applications but at the cost of significantly reduced throughput.

[5] Estimated value only, VDL4 DLS has not yet been simulated.

[6] Although AMSS supports all 15 levels of priority specified by the ITU, it should be noted that only 6 relate to safety and regularity of flight. These 6 are applicable to the AMS(R)S allocation.

[7] Channel Rate is the rate at which information is modulated on to the carrier and does not imply an effective rate of transfer for user data.

[8] The 10,500 kbps channel is only available is a high gain (Aero-H) antenna is fitted.

5.2.1.4 It has been assessed that the end-to-end architecture, apart from the datalink segment, can cope with the levels of priority, integrity, availability, message frequency, throughput and capacity typically required by ATM point-to-point technologies, with the conditions presented in Annex B.

5.2.1.5 In fact, the end-to-end architecture can include QoS management mechanisms in upper-layer protocols that will improve the end-to-end performance of the system, particularly concerning:

- Priority: end-to-end priority management mechanisms redress the datalink technology shortcomings.
- Integrity: upper-layer QoS management mechanisms, at the transport layer for instance, can improve the integrity, although they also increase the amount of data exchanged.

5.2.1.6 The key performance criteria are time delay and throughput, which determines the number of frequencies required to support the applications.

Transit delay

5.2.1.7 The following table summarises the transit delay requirements for the various requirements categories along with the ability of each technology to meet those requirements.

Requirements Category	Transit Delay[9]		HFDL	AMSS	VDL2	VDL3	VDL4
	95%	99.996%					
ADAP-0	10 s	20 s	No	Possibly	Yes	Yes	Yes
ADAP-1	5 s	15 s	No	No	Possibly	Possibly	Possibly
D-FIS-0	10 s	20 s	No	Possibly	Yes	Yes	Yes
ADS-C-0	30 s	60 s	No	Yes	Yes	Yes	Yes
ADS-C-1	10 s	20 s	No	Possibly	Yes	Yes	Yes
CPDLC-0	5 s	10 s	No	No	Possibly	Possibly	Possibly
CPDLC-2	30 s	60 s	No	Yes	Yes	Yes	Yes
CPDLC-3	10 s	15 s	No	No	Yes	Yes	Yes

Table 5-2: Meeting transit delay requirements

5.2.1.8 The 7.5-seconds transit time attributable to the ground-ground architecture elements means that it is not possible to achieve a 5 second transfer in 95% of cases.

5.2.1.9 The issue in supporting ADAP-0 (e.g., CAP, SAP), CPDLC-0 (Strategic Pilot-Controller Dialog), CPDLC-3 (Trajectory negotiation, e.g. FLIPCY, COTRAC) is the trade-off between the use of specific architecture dedicated to time-critical exchanges and the adaptation of operational procedures and operational requirements.

[9] End-to-end transit delay which includes 7.5 seconds which are not attributable to the datalink.

Throughput

5.2.1.10 The effective data rate achieved by each channel is dependant upon many factors such as modulation scheme, channel coding, parity checking, length of sync bursts and unique words, and forward error correction mechanisms.

5.2.1.11 One of the most important considerations in aeronautical communications is the access scheme. The impact of hidden terminals will reduce the effective throughput for media using random access techniques (VDL2 and VDL4). During the study, it has become clear that insufficient simulations have been conducted to accurately predict the effective throughput for the proposed VHF media. Urgent action is required to rectify this.

5.2.1.12 High fidelity simulations of large scale (wide area) scenarios are required, similar to those carried out as part of the TLAT exercise for broadcast media, to accurately determine the channel requirements.

5.2.1.13 The following table summarises the throughput calculations performed in the study based on an average data size of 128 bytes. Detailed explanations are given in the relevant annexes.

	VDL2 (ST15)	VDL2[10]	VDL3 (3V1D)	VDL3 (3T)	VDL4[11]
Surface	5335	9734	4100	12 400	14000
Terminal	5335	3454	4100	12 400	14000
En-Route	5335	2800	4100	12 400	14000

Table 5-3: Effective data rates

5.2.1.14 Two values have been presented for VDL Mode 2. The first was taken from the ST15 study. Comments received during the public consultation process indicate that these values should no longer be considered valid. The second value presented is based on work internal to the project and is consistent with previous simulation work undertaken on behalf of Eurocontrol.[12]

5.2.1.15 Values have been presented for two channel configurations for VDL3. The 3V1D configuration provides three voice channels and one data channel from a single 25 kHz channel. This configuration forms the basis of the FAA plans. The 3T configuration, in which the entire 25 kHz channel is dedicated to data. This configuration is more likely in Europe.

[10] Based on analysis performed in this study, see annexes

[11] During the public consultation process, Eurocontrol commented that a reasonable effective data rate for VDL4 is 12-14000 bps. Simulations are required to verify this figure.

[12] During the consultation process, comments were received that effective data rates greater that 12 kbps have been measured during VDL2 trials with a single aircraft and could be improved upon by tuning the protocol parameters. The values presented here are an estimate based on a representative load assuming 90% equipage in the year stated.

5.2.1.16 The following table indicates the total throughput required in bits per second within each homogenous zone assuming a high level of equipage (90%) for the stated years.

Region	Step 1 (2005)	Step 2 (2010)	Step 3 (2010)	Step 4 (2010)	Step 5 (2015)
Surface	2,133	2,133	2,133	4,933	5,267
Terminal	4,669	27,511	27,511	33,276	63,158
En-Route	12,751	48,114	48,114	63,000	118,782

Table 5-4: VDL throughput requirements

5.2.1.17 Table 5-5 indicates the number of channels required to support the throughput for each candidate VHF media assuming all applications are supported.

5.2.1.18 The value presented does not include guard bands. Frequency planning criteria have only been developed for VDL2, which requires a guard band between operational channels. Similar criteria are expected for VDL3 which also uses a 31.5 kHz channel coding. According to information from CNS Systems, for VDL4, which uses 19.5 kHz channel coding guard bands may not be required. Further work is required to verify this assumption.

Media	Region	**Step 1 (2005)**	**Step 2 (2010)**	**Step 3 (2010)**	**Step 4 (2010)**	**Step 5 (2015)**
VDL2 (ST15)	Surface	1	1	1	1	1
	Terminal	1	6	6	7	12
	En-route	3	10	10	12	23
	Total	**5**	**17**	**17**	**20**	**36**
VDL2	Surface	1	1	1	1	1
	Terminal	2	8	8	10	19
	En-route	5	18	18	23	43
	Total	**8**	**27**	**27**	**34**	**63**
VDL3 (3V 1D)	Surface	1	1	1	2	2
	Terminal	2	7	7	9	16
	En-route	4	12	12	16	29
	Total	**7**	**20**	**20**	**27**	**47**
VDL3 (3T)	Surface	1	1	1	1	1
	Terminal	1	3	3	3	6
	En-route	2	4	4	6	10
	Total	**4**	**8**	**8**	**10**	**17**
VDL4	Surface	1	1	1	1	1
	Terminal	1	2	2	3	5
	En-route	1	4	4	5	9
	Total	**3**	**7**	**7**	**9**	**15**

Table 5-5: VDL channel requirements (high usage)

5.2.1.19 As the number of channels is higher than expected, it is recommended that:

- Air Derived Data requirements are met by Mode S Enhanced Surveillance;
- Voice rather than enhanced ACL is used to initiate ASAS applications.

5.2.1.20 Table 5-6indicates the number of channels required to support the throughput for each candidate VHF media under the reduced loading criteria.

Media	Region	**Step 1 (2005)**	**Step 2 (2010)**	**Step 3 (2010)**	**Step 4 (2010)**	**Step 5 (2015)**
VDL2 (ST15)	Surface	1	1	1	1	1
	Terminal	1	2	2	3	6
	En-route	3	3	3	6	15
	Total	**5**	**6**	**6**	**10**	**22**
VDL2	Surface	1	1	1	1	1
	Terminal	2	2	2	4	10
	En-route	5	6	6	11	29
	Total	**8**	**9**	**9**	**16**	**40**
VDL3 (3V1D)	Surface	1	1	1	2	2
	Terminal	2	2	2	3	8
	En-route	4	4	4	8	20
	Total	**7**	**7**	**7**	**13**	**30**
VDL3 (3T)	Surface	1	1	1	1	1
	Terminal	1	1	1	1	3
	En-route	2	2	2	3	7
	Total	**4**	**4**	**4**	**5**	**11**
VDL4	Surface	1	1	1	1	1
	Terminal	1	1	1	1	3
	En-route	1	2	2	3	6
	Total	**3**	**4**	**4**	**5**	**10**

Table 5-6 VDL channel requirements (low usage)

5.2.1.21 It should be noted that:

- The number of channels required will be lower in early years due to lower equipage levels.
- The calculations are based on average throughput requirements, however the peak throughput requirements would be higher, and additional channels may be needed to cope with peak demand.
- The number of channels required is greater than currently allowed for. At least 9 VDL2 channels will be required prior to 2010, excluding the two channels dedicated to AOC and guard bands. .
- The use of VDL4 or VDL4 could significantly reduce the burden on the VHF channels
- **Simulations are required urgently to fully assess this issue.**
- VDL2 does not support the requirements for Step 4 due to the lack of priority management and deterministic QoS
- Delaying step 4 until a broadband solution is available may be necessary.
- VHF media will not support Step 5b.

5.2.1.22 AMSS and HFDL provide beyond-line of sight communications and are the current datalinks for remote and oceanic regions. Together, they are able to provide sufficient bandwidth and Quality of Service for all five steps in the application roadmap for Oceanic areas.

5.2.2 Maturity assessment

5.2.2.1 The following table summarises the maturity of all the nine point-to-point technologies, following the characteristics used in the Annexes.

Technologies	Standards	Airborne and ground equipment	Frequency	Conclusion
HFDL	MASPS and MOPS available	Systems already operational	Up to 4 channels available for each ground station in the band 2-32 MHz (e.g. 4 channels for Reykjavik station)	*Mature Operational System*
AMSS	SARPs, MASPS, MOPS published ARINC 741	Systems already operational	Global allocation	*Mature Operational System*
VDL2	SARPs, MASPS published	Existing prototypes	136,975 MHz dedicated for VDL2 Data 4 frequencies expected in future plans	*Limited operational use in US. Operational trials (PETAL, LINK) in Europe.*

Technologies	Standards	Airborne and ground equipment	Frequency	Conclusion
VDL3	SARPs, MASPS, MOPS published	Existing prototypes Operational equipment under development	No assigned frequencies in Europe	*Tests by FAA ending October 2004*
VDL4	A new version of SARPS for the DLS has recently been validated.	Prototype Systems already operational	139,950 MHz channel for VDL4 tests[13]	*Simulations and trials of DLS required.*
GATELINK	AEEC Characteristic but no SARPs or MOPS	Operational Equipment Exists	Principally 2.4 GHz	*Mature System, but standardised for safety applications*
NGSS	Generic SARPs, MOPS published. No technology specific material published	Operational system	L-, Ku- and Ka-band	*Operational system*
SDLS	No specific activity, reuse of AMSS and NGSS standards possible	R&D only	867 KHz bandwidth	*No deployment plans*
Boeing CS	Boeing specific system, no foreseen standards	Equipment is available	Frequency available	*System not operational but under trials between several airlines and Boeing*
3G	No Activity	R&D Only	Requires ITU co-ordination	*No deployment plans*

Table 5-7: Maturity assessment for point-to-point media

5.2.2 In terms of maturity, VDL2 can be considered an operational system. Both VDL3 and VDL4 are still trials systems. The latest version of the VDL4 point to point protocol requires flight trials.

[13] The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there are no regulatory impediments against applying VDL Mode 4 as a data link supporting CNS applications.

5.2.3 Complexity assessment

5.2.3.1 The following table summarises the key findings of the complexity assessment of the point-to-point media.

Technology	Issues
HFDL	No remaining issues
AMSS	The avionics and in particular the antennae are large and costly for the Aero-H service, this has been addressed by service enhancements and in particular by Aero-I. The ground segment requires 12m dishes which are expensive and tend to be operated by communications service providers.
VDL2	VDL Integration with DSB-AM voice and other VDLs is still an issue. VDL2 is seen by some as less of an issue due to the sporadic nature of transmissions (i.e. only one radio operates at once). The frequency management criteria for VDL2 include a guard band between operational frequencies.
VDL3	VDL Integration with DSB-AM voice and other VDLs is still an issue. Frequency planning criteria are unknown.
VDL4	VDL Integration with DSB-AM voice and other VDLs is still an issue. Frequency planning criteria are unknown
NGSS	No known issues
SDLS	R&D Only
Boeing CBS	R&D Only
3G	R&D Only

Table 5-8: Complexity assessment for point-to-point technologies

5.2.3.2 Integration of multiple VHF radios on an airframe is a complicated issue which was discussed at the second stakeholder workshop[14]. The workshop agreed that further work was required to clarify the issue and that consideration of the analogue voice radios was also required.

5.2.3.3 The problem is that inter-modulation products created when a VDL operates interfere with the DSB-AM radio. ARINC-716 requires a 6MHz separation between the voice channel and the VDL channel. ACARS and VDL2 have be shown to interfere with DSB-AM voice but in a manner that is said to be acceptable. The contention is that the periodic nature of VDL3 and VDL4 transmissions implies that the use would not be safe.

5.2.3.4 ICAO [268] identified the co-site problem during the standardisation of VDL2 as an implementation issue to be resolved by industry. An Ad Hoc Working Group of the

[14] The following discussion is based on submission from LFV, Marconi, CNS Systems and Comm4Solutions.

Data link Subcommittee of the Airlines Engineering Committee (AEEC) addressed the issue and reported their findings to ICAO. AEEC concluded that interference from VDL in to the DSB-AM receiver were not worse than those due to interference from Aircraft Communications Addressing and Reporting System (ACARS) that has been in operation onboard aircraft for many years. It was noted that these implementations included both adaptive S/N squelch and dynamic RF attenuation. [269]. Without these techniques it was highly probable that performance of closely spaced DSB-AM with on-board VDL or ACARS would not be acceptable.

5.2.3.5 At the second workshop it was suggested by Eurocontrol that VDL4 interference would be the same when operated as a point-to-point datalink, but that further work was required for ADS-B. Eurocontrol are currently conducting a study on VDL Mode 4 Architectures [263] and [264].

5.2.3.6 The problem is also dependent on the modulation scheme of the VHF Data Link to be used. Comments from Comm4Solutions suggest that most sensitive datalink is VDL2 using the D8PSK modulation scheme; whilst the most robust one is VDL4 using the GFSK modulation scheme.

5.2.3.7 VDL4 prototype equipment has been tested onboard various types of aircraft without any major co-site problem being identified. However, it should be noted that not all VHF frequencies have been tested and unwanted harmonics might occur in limited parts of the VHF spectrum. Partially “muting” DSB-AM receivers during data link transmissions seams to be operationally acceptable. This possibility should be further studied in order investigate:

- the full impact on DSB-AM operations; and
- the level and length of muting required taking into account the length of data link transmission and the impact of ramp-up and ramp-down of the digital radios. If muting would be required only during ramp-up, it would probably not affect the DSB-AM system at all.

5.2.3.8 Another co-site issue is the interference between VDLs. If more than one VDL is operating onboard an aircraft simultaneously, all receptions would be blocked during transmissions of one VDL system as well as simultaneous transmissions would interfere with each other. The solution to this problem is to avoid simultaneous VDL activities by having an external “managing function” or only allow one VDL system onboard aircraft. The VDL4 standard requires that all transmissions on VDL4 frequencies are coordinated in order to avoid unintentional interference. It was also suggested that the specification of the current analogue voice radio should be revisited.

5.2.3.9 It was noted that a major improvement on voice radios has been just recently applied through the introduction of the 8.33 frequency spacing and of the FM immunity requirement. As mandated by ICAO, all the radios and the landing equipments have been equipped with a specific filter to reduce interferences effects of the FM broadcasting radios. It therefore follows that a similar process could be possible also to allow the introduction of one of datalink technology which is expected to lead to improvements in the ATM

5.2.3.10 It is also noted that sophisticated co-siting technologies, such as dynamic filtering, that have been already developed in other fields, could be used in a cost effective manner in the civil aviation required.

5.2.3.11 It was also noted that a transition to digital voice is also the only means to improve Security and reliability of the aeronautical communications that is in the end to improve the safety of the aeronautical transportation. In other domains, digital voice is consolidated, sound, mature and cost effective technology.

5.2.3.12 At this stage the debate is unresolved. Further work is required to clarify the issue. At the workshop Airbus stated that they had stopped work on VDL4 until this issue is resolved.

5.2.3.13 These issues indicate that in meeting the operational needs of the future ATM environment, it seems that the integration of CNS systems will support resolution of co-site issues, security aspects, data link management, reduction in costs for equipment and logistics.

5.2.4 Cost assessment

5.2.4.1 Table 5-9 summarises the ground system costs for the point-to-point technologies with no satellite component, excluding 3G which is in too early a stage of development for cost estimation.

5.2.4.2 The costs include the ground station (transceiver + antenna), but exclude the network and ATC centre upgrade costs. A detailed description of the approach used in deriving these costs is given in Annex C.

Costs in euro	**HFDL**	**VDL2**[15]	**VDL3**	**VDL4** **Point-to-point**
Baseline assumed	Existing HF voice ground station	Existing ground station site	Existing ground station site	
Cost of ground station	48,000	60,000	150,000	110,000
Installation	9,600	12,000	30,000	22,000
Total initial cost per ground station (1 transceiver)	**57,600**	**72,000**	**180,000**	**132,000**
Yearly maintenance costs per ground station (1 transceiver)	4,800	6,000	15,000	11,000
Number of ground stations required in Europe	20	150	150	150
Total ground station costs (1 transceiver)	**1.2 million**	**10.8 million**	**27.0 million**	**19.8 million**

Table 5-9: Ground costs for point-to-point technologies

5.2.4.3 Table 5-10 summarises the non-aircraft system costs for the point-to-point technologies with a satellite component. The ground costs include the ground earth stations (GESs), the cost of the satellites, and the satellite launch costs, but

[15] It should be noted that VDL2 will be deployed by ARINC and SITA. ATS providers may opt to provide VDL2 through this infrastructure and not incur the initial capital outlay but instead pay fees to ARINC or SITA.

exclude the network and ATC centre upgrade costs. A detailed description of the approach used in deriving these costs is given in Annex C.

Costs in euro	**AMSS**	**NGSS**	**SDLS**
Baseline assumption	n/a	n/a	Existing ground station site
Cost of ground station	15,000,000	15,000,000	1,000,000
Installation	3,000,000	3,000,000	200,000
Total initial cost per ground station	**18,000,000**	**18,000,000**	**1,200,000**
Yearly maintenance costs per ground station	1,500,000	1,500,000	100,000
Number of ground stations required	3	30	40
Total ground station costs	**54,000,000**	**540,000,000**	**48,000,000**
Satellite build costs (per satellite)	140,000,000	25,000,000	140,000,000
Satellite launch cost (per satellite)	70,000,000	15,000,000	70,000,000
Project management cost per satellite (100 euro/hour)	10,000,000	4,000,000	10,000,000
Total initial cost per satellite	**220,000,000**	**44,000,000**	**220,000,000**
Number of satellites required	3	88	2
Total satellite cost	**660,000,000**	**3,872,000,000**	**440,000,000**
Total system cost (satellites plus ground stations)	**714 million**	**4412 million**	**488 million**

Table 5-10: Ground costs for point-to-point technologies with satellite component

5.2.4.4 Table 5-11 and Table 5-12 summarise the airborne costs for the point-to-point technologies. A detailed description of the approach used in deriving these costs is given in Annex C.

Costs in euro	**HFDL**	**VDL2**	**VDL3**	**VDL4** **Point-to-point**
Baseline assumed	HF voice or no HF	No CMU previously installed	CMU previously installed	CMU previously installed
Hardware				
Cost of transceiver	59,100	49,400	56,500	45,000
Antenna (x 2)	n/a	n/a	2,000	2,000
Upgrade of Radio Control Panel (RCP) x 2	n/a	n/a	19,000	n/a
Communications Management Unit (CMU)	n/a	47,000	n/a	n/a
Upgrade of Communications Management Unit (CMU)	n/a	n/a	8,000	8,000
Upgrade of Data Link Control Display Unit (DCDU)	n/a	n/a	6,000	n/a
Integration, installation & certification				
Installation kit(s)	2,955	4,820	4,275	3,325
Service bulletin	5,910	9,640	8,550	6,650
Man-hours (80 euro/hour)	2,955	4,820	4,575	3,325
Total initial costs per aircraft (1 transceiver)	**70,920**	**115,680**	**108,900**	**79,800**
Yearly maintenance costs per aircraft (1 transceiver)	5,910	9,640	9,150	6,650

Table 5-11: Airborne costs for the point-to-point technologies (part 1)

Costs in euro	AMSS	NGSS	SDLS
Baseline assumption	n/a	n/a	n/a
Hardware			
Cost of transceiver	179,392	29,500	179,392
Integration, installation & certification			
Installation kit(s)	8,970	1,475	8,970
Service bulletin	17,939	2,950	17,939
Man-hours (80 euro/hour)	8,970	1,475	8,970
Total initial costs per aircraft (1 transceiver)	**215,270**	**35,400**	**215,270**
Yearly maintenance costs per aircraft (1 transceiver)	17,939	2,950	17,939

Table 5-12: Airborne costs for the point-to-point technologies (part 2)

5.2.5 Industrial assessment

5.2.5.1 Table 5-13 summarises the essential findings of the industrial assessment of the point-to-point media.

Technology	Issues
HFDL	Operational system supported globally by ARINC for ACARS, with avionics provided by Rockwell Collins. Future enhancements are likely.
AMSS	Operational system supported globally by ARINC and SITA for ACARS and used by FANS1/A. Inmarsat provides the space segment. Service extensions are foreseen.
VDL2	Supported globally by ARINC and SITA for AOA. Eurocontrol and FAA have significant evaluation and deployment projects ongoing. (Link2000_ and CPDLC Build 1). Airbus are able to offer VDL2/AOA now and VDL2/ATN by 2003.
VDL3	Cornerstone of the FAA NEXCOM Project with significant evaluations planned. Currently no European interest.
VDL4	VDL4 is mature as a broadcast technology and nearly mature for point-to-point communications. Comm4Solutions are proposing an AOC network using VDL4. Several avionics manufacturers are developing equipment.
NGSS	The initial NGSS, ICO, Iridium and Globalstar, have all suffered financially from the loss of market share to terrestrial mass personal communications providers. This has led to significant concerns over the proposed business model, which is no longer accepted as suitable for the provision of safety of life services. Architecture studies of NGSS (eg EMERTA) have shown that they do offer a feasible technical solution.
SDLS	SDLS is a research programme supported by ESA. Eurocontrol have re-used some elements of SDLS in their NexSat programme. No other industry or aviation stakeholder indicated support for this technology during the assessment phase.
Boeing CBS	No support for ATS use.

Technology	Issues
3G	Support from Eurocontrol and IATA. No known integration problems Although this technology is in the early development stages for aviation use, it is well understood from use in other domains and represents a lower risk development than aviation specific technologies.

Table 5-13: Industrial assessment for point-to-point media

5.2.6 Conclusions of technical assessment

5.2.6.1 In Europe, the two obvious choices for an initial air-ground datalink are VDL2 and VDL4. VDL2 is the more mature technology in terms of point-to-point functionality and has been selected for deployment for AOC by ARINC and SITA and for ATS in the Link2000+ programme by Eurocontrol. VDL2 does not provide efficient use of scarce VHF channels and is not suited to the provision of time critical applications. However, the initial deployment of VDL2 is fully supported by this study.

5.2.6.2 Significant work is required to verify the claims made for VDL4, however, it is likely to provide more efficient use of the bandwidth. VDL4 has support in Scandinavia, Russia and amongst the Low Cost and General Aviation community. An AOC network is being proposed.

5.2.6.3 VDL3 would offer an alternative route, but the deployment of 8.33kHz voice in Europe means that the migration plans being developed by the FAA are not applicable to European airspace.

5.2.6.4 For beyond line of sight communications, the existing AMSS and HFDL data links are seen as sufficient until at least 2015.

5.2.6.5 A broadband solution for aviation is needed in the period 2012 to 2015 if the application roadmap is to be delivered. Of the currently proposed solutions, 3G, both terrestrially and via satellite are recommended for further research.

5.2.6.6 The deployment of gatelink is considered to be a local issue between aircraft and airport operators[16].

5.3 Roles in the datalink roadmap

5.3.1 Purpose

5.3.1.1 The purpose of this section is to consider technology selection for each step of the application roadmap.

5.3.2 Step 1: Early a/g ATM applications.

5.3.2.1 This step requires the deployment of an initial air-ground datalink; however, during this stage, voice will be used for all tactical pilot-controller dialog.

[16] During the public consultation, Easy Jet indicated that Gatelink is an important enabler of CDM and should be considered with European datalink programs.

5.3.2.2 The two potential candidates are VDL2 and VDL4.

5.3.2.3 VDL2 is the more mature system, but doubt has been raised over the spectral efficiency achieved. VDL2 is currently being deployed by ARINC and SITA to support AOC (using the ACARS over AVLC (AOA) service.

5.3.2.4 Initial modelling of VDL4 indicates that fewer frequencies would be required; however, VDL4 is not mature as point-to-point media and deployment is not anticipated until 2006.

5.3.2.5 Comm 4 Solutions has proposed the use of VDL4 for AOC. Such an initiative could be supported to increase competition for AOC services.

5.3.2.6 AMSS and HFDL are sufficient for oceanic and remote airspace requirements.

5.3.2.7 Gatelink should be deployed during this stage to support aircraft communications at the gate. Primarily gatelink will be used for non-ATS communications, however its use for ATS should be supported.

5.3.3 Step 2: ATM applications related to downlink of air-derived data.

5.3.3.1 This step could be achieved by the use of additional datalink applications (CAP and SAP) or the deployment of a downlink broadcast media. Given the shortage of VHF spectrum it is recommended that broadcast media be used for this stage.

5.3.4 Step 3: Introduction of spacing.

5.3.4.1 The introduction of ASAS applications could involve initiation by voice or enhanced ACL. Although the data requirements are low for these applications it is still recommended that voice be used.

5.3.5 Step 4: Extension of a/g ATM applications.

5.3.5.1 This step involves additional air-ground datalink applications; it could involve the deployment of a new technology or just additional frequencies.

5.3.5.2 Where VDL2 is used for Step 1, 16 operational channels are required (including guard bands this would be 31 frequencies) to support high equipage of the predicted traffic densities. Only five frequencies (plus guard bands) would be required if VDL4 is chosen for Step 1.

5.3.5.3 However, given recent decisions it is anticipated that VDL2 will be deployed for Step 1. The question for Step 4 is then if the additional deployment of either VDL3[17] or VDL4 could reduce the need for VHF frequencies such that saturation does not occur before Step 5b.

5.3.5.4 Deployment would require significant level of equipage and a transfer of some VDL2 ATS frequencies to the new VHF media. The frequency management issues would be significant.

[17] In this instance, VDL3 would be deployed as a wide area data network (3T mode) not as a voice/data service (3V1D mode).

5.3.6 Step 5b: Conflict free trajectory negotiation

5.3.6.1 Conflict free trajectory negotiation will require an enhanced air-ground datalink.

5.3.6.2 The key challenges beyond 2015 are:

- To support time critical ATC messages
- To support continued voice operation
- To support high bandwidth requirements for non-ATS applications[18].

5.3.6.3 A number of advanced media have been considered, namely:

- AMSS Enhancements such as Swtift64 and Aero-GAN
- NGSS
- SDLS
- 3G

5.3.6.4 Of these, a combination of terrestrial 3G and the AMSS enhancements, especially the use of 3G protocols, is likely to offer the most beneficial combination and should be supported by research urgently.

5.3.6.5 This solution supports a highly capable pipe to the aircraft which could be used for ATC, non-ATS applications, including passenger voice and Internet access and ATS voice. Research is required to support the certification of such a system.

5.3.6.6 The present NGSS, namely ICO, Iridium and Globalstar, have been discounted due to the financial difficulties of their operators leading to concern over the long-term provision of an aeronautical service.

5.3.6.7 Future NGSS should not be ruled out. Satellite technology is able to offer significant improvements on the performance of the current AMSS (Aero-H). Eurocontrol have recently started a programme, NexSat, which re-uses elements of SDLS to provide AMSS services at L-band. Other satellite solutions are also possible, including systems at Ka- and Ku-band. Research is required to define the most cost effective way of providing satellite services.

5.3.6.8 It should also be noted, that Boeing ATM [250] are designing a satellite system with communications and navigation payloads specifically for aviation use referred to as Global Communications, Navigation and Surveillance System (GCNSS). The FAA is supporting this activity.

[18] Higher bandwidth is required to support enhanced ATS and AOC applications, but genuine “Broadband” (eg greater than 64 kbps) communications may only be required to support passenger applications.

5.4 Conclusions

5.4.1 The following table summarise the key points on each technology:

Technology	Points of Interest / Role in Datalink Roadmap
HFDL	▪ The existing HFDL is the only current system capable of covering north polar routes. ▪ HFDL is hindered by very low data rates, but does support basic FANS1/A type applications and ACARS (ARINC). ▪ HFDL is retained in the roadmap for current use; but with long term replacement by future satcom possible.
AMSS	▪ AMSS is an existing system capable of providing narrow band data (throughput is approximately equal to VHF but transfer delay is much longer). ▪ Currently AMSS is used to support FANS1/A but also includes an ATN sub-network. ▪ AMSS is fitted to 2000+ mainly long haul aircraft. ▪ AMSS is hindered by high cost for avionics and communications charges. The price per kilobit could be lower if the system was used more. ▪ Retained for current use; replacement by future satcom is likely. Consideration of ATS use for Inmarsat-4 and Inmarsat-5 services is urgently required.
VDL2	▪ Significant deployment plans for VDL2/AOA and VDL2/ATN within the Link2000+ and FAA CBDLC/Build 1 programmes ▪ The effective data rate for VDL2 is of order 3000 bps for en-route airspace (see technology assessment document P167D2020 Section 5 and Annex F for a discussion of this data rate). ▪ VDL2/ATN is the first continental ATC datalink, but will require up to 9 operational channels by 2010. ▪ More details flight trials results are on-going to measure effectively how far VDL2 can correctly support CPDLC demanding applications (in PETAL II report, 95 % end-to-end dialogue time is 80 seconds for CPDLC). Flight trials results should confirm whether delivery of conflict-free trajectories be supported by VDL2. It is unlikely due to the required volume of information e.g., COTRAC). ▪ Due to the lack of deterministic-QoS and priority mechanisms, VDL2/ATN does not support long term goal of tactical datalinks. ▪ Supported for use as VDL2/AOA and VDL2/ATN for ATC.

Technology	Points of Interest / Role in Datalink Roadmap
VDL3	▪ Significant support in US where VDL3 is expected to be the next generation technology for both ATS voice and data. AOC data would remain on VDL2 ▪ Subject to meeting NARC Criteria, VDL3 is expected to be initially deployed to provide digitised voice for high altitude en-route airspace in the 2009 timeframe. ▪ The FAA does not expect to introduced VDL3 for data until around 2012 ▪ No support in Europe where 8.33 kHz voice is being implemented to redress shortage of voice channels; Europe does not have a long term strategy for voice. ▪ The combined voice and data makes VDL3 an attractive option for future deployment in the US; particularly as an ANSP replacing it's voice infrastructure will effectively be deploying a datalink infrastructure. ▪ If deployed in Europe, VDL3 would have to be deployed as a wide area data-link (3T-mode).
VDL4	▪ VDL4 has only just been standardised for point-to-point communications, the DLS protocols were accepted by AMCP/8 as validated subject to flight trials. ▪ Maturity of avionics and ground stations is supported by the maturity of products for broadcast services. ▪ Integration of VDL4 onto a airframe already supporting VHF voice and VDL2 is still an issue. ▪ The effective data rate for VDL4 is 14 kbps (see technology assessment document P167D2020 Annex J for a discussion of this data rate) ▪ VDL4 is suited to the provision of an AOC communications for Regional and General Aviation operators who have not yet invested in ACARS. This is because fleet management applications are a natural consequence of the exchange of position in the system messages. ▪ The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there are no regulatory impediments against applying VDL Mode 4 as a data link supporting C, N and S applications.
Gatelink	▪ A number of technologies have been proposed over the years for providing very high bandwidth communications for parked aircraft. The majority of the communications does not relate to ATC, although some clearances, including advanced slot management applications could be supported. ▪ Gatelink is an important enabler of Collaborative Decision Making (CDM). ▪ A European decision for a particular technology could support lower prices in the long term.

Technology	Points of Interest / Role in Datalink Roadmap
NGSS	▪ A number of potential NGSS, including Iridium, ICO and Globalstar, have been proposed over the years. These systems have their roots in mass personal communications. Only Iridium is still hopeful of providing an aeronautical service and is currently used for voice services by General Aviation in the US. ▪ The continued operational and financial difficulties of NGSS operators (due to the failure of their core non-aviation market) make them unattractive for commercial aviation. ▪ Current systems (ICO, Iridium and Globalstar) are not retained for inclusion in the roadmap. ▪ Future NGSS could be an important part of the aeronautical communications infrastructure.
SDLS	▪ SDLS is a research project sponsored by ESA ▪ Eurocontrol are developing a program called NexSat which reuses certain aspects of the SDLS programme. ▪ The design brief is to replicate VHF communications (voice and data) using a geo-stationary satellite. ▪ In its first guise, it would reuse existing Inmarsat infrastructure but use CDMA to improve services.
Boeing CS	▪ Broadband system capable of live TV to aircraft but has not been proposed for safety services. ▪ Not retained for inclusion in the roadmap
3G	▪ The aeronautical application of 3G is being researched by Eurocontrol, and the potential to offer significant advantages over VHF communications. ▪ Retained for use in Step 3. Significant research should be conducted into the best way of using 3G for aviation. This research should include security concerns of the use of a single channel to support all aircraft communications needs.

6 Broadcast technologies

6.1 Purpose

6.1.1 This section assesses the relative merits of the candidate broadcast technologies, namely:

- 1090 Extended Squitter
- VDL4
- Universal Access Transponder
- Mode S Enhanced Surveillance

6.1.2 Full descriptions of these technologies are provided in the Annexes.

6.2 Technology assessment

6.2.1 Capability assessment

6.2.1.1 Technical details of the candidate technologies are provided in the Annexes. A comparison of the three ADS-B technologies has recently been performed by Eurocontrol and the FAA [152] and [259]. The conclusion of these technical assessment are:

- 1090 ES:
  - Supports ranges of 40 Nm in Core Europe for 2010.
  - Does not support ranges of 40 Nm in Core Europe for 2015 and beyond without a significant reduction in FRUIT.
  - Supports ranges of 100 Nm in low-density airspace, but does not meet the 120 Nm requirements.
  - The required frequency is available but is also used for TCAS and SSR.
- For VDL4:
  - Capacity issues prohibit sole use in the Core European 2010 scenario,
  - VDL4 does provide 120nm ranges in low-density airspace.
  - Eurocontrol are continuing to investigate the combined use of 1090 ES and VDL4 to support operation beyond 2010.
  - The deployment of VDL4 will require global, regional and local allocations of suitable frequencies. Depending upon the chosen role, 4 to 7 25 kHz channel will be required which could be in either the COMM or NAV bands. International co-ordination at ITU-level will be required. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position.

Subsequently there will be no regulatory impediments against applying VDL Mode 4 as a data link supporting CNS applications.

- Earliest availability: 2006

- For UAT:

  - The most recent simulations indicate that all requirements can be met with the exception of the very longest reception range.

  - This work has been published in the US [144] Preliminary Eurocontrol analysis confirms the US results.

  - The deployment of UAT requires international co-ordination to obtain a 3MHz channel in the DME band. Whilst a suitable frequency seems likely to be available in America, the European situation is more complex. This is due to:

    - Future requirements for an additional 180-200 DMEs to support the proposed RNP RNAV mandate [258].

    - The need to co-ordinate across all 41 ECAC states.

  However, the US has already identified a frequency (978 MHz, the lowest DME frequency that can be coordinated on an international basis) which is paired with the 108MHz VOR frequency. In general, 108 MHZ is not used due to the problems associated with the sound broadcasting services directly below it. Therefore, it is possible that the DME frequency identified for UAT could be made available on a global basis. An investigation of this frequency in Europe [147] found that whilst it was not heavily used (6 allocations) it was difficult to reassign these allocations within the DME band. This investigation did not consider the need for additional DMEs in Europe.

6.2.1.2 In addition Mode S ES is capable of supporting all Air-Ground (enhanced surveillance) and TIS-B ground-air broadcast requirements but is not suitable for FIS-B.

6.2.1.3 The current definitions of the ADS-B media do not support enhanced surveillance (APP1a, APP1b and APP1c) as the current message definitions do not contain the parameters specified by Mode S Enhanced Surveillance [165]. The following table summarises the airborne parameters for enhanced surveillance.

Parameter	D/L Service	Mode S ES	1090 ES	VDL4	UAT
Magnetic Heading	CAP	Yes	No	No	No
Air Speed (IAS and MACH Number)	CAP	Yes	No	No	Yes
Selected Altitude	CAP/SAP	Yes	(TCP)	(TCP)	(TCP)
Vertical Rate	SAP	Yes	Yes	Yes	Yes
Track Angle Rate	SAP	Yes	Yes	No	No
Roll Angle	SAP	Yes	No	No	No
Ground Speed	SAP	Yes	Yes	Yes	No
True Track Angle	SAP	Yes	No	No	No

6.2.1.4 Hence, the ADS-B media can be used to support elementary surveillance, but not enhanced surveillance as currently defined. Re-definition of the ADS-B messages sets is not complex issue, but does take time for all the standards to be updated.

6.2.2 Maturity assessment

6.2.2.1 The following table summarises the maturity of 1090 Extended Squitter.

Stage	Issues
System Development	A large number of simulations have been conducted which demonstrate that 1090 ES could be deployed without adversely effecting TCAS and SSR operation. However, further simulations will be required to consider operation of ADS-B in an enhanced surveillance environment. Major flight trials have been conducted in: ▪ Germany ▪ US (Operational Evaluations in Ohio Valley) In addition, Australia has recently commenced an operational trial of 1090 ES to support ground surveillance.
Standards Development	MOPS: ED-102/DO-260 Originally published in November 2000. Update to DO-260 published January 2002. SARPS: Published, but may need updating to reflect recent MOPS changes. AEEC: Complete. Standards work complete by 2002, with exception of possible SARPs updates.
Equipment Development	Equipment is already available. In response to the Mode S Elementary Surveillance mandate, and the expected Enhanced Surveillance mandate, Airbus and Boeing are certifying Mode S transponders with Elementary Surveillance, Enhanced Surveillance, and 1090 Extended Squitter ADS-B Out functions, along with the requisite aircraft installation wiring. Initial deliveries and service bulletins for in-service aircraft will start in the first quarter of 2003, in support of fleet wide compliance by 2005.
System Deployment	Significant deployment plans in FAA. Institutional support in Europe. No firm plans from ANSPs
Conclusion	1090 ES has reached full maturity. Operational deployment could begin within 12 months and be widespread by 2006.

Table 6-1: 1090 ES maturity assessment

6.2.2.2 The following table summarises the maturity of VDL4.

Stage	**Issues**
System Development	Significant demonstrations of VDL4 supporting air-air, air-ground and surface surveillance have been conducted in Europe, including: NEAN, NAAN, NUP MFF and MEDUP. A significant number of aircraft have been equipped with early VDL4 avionics. A number of VDL4 ground stations exist due, inter alia, to the NEAN/NUP programmes
Standards Development	MOPS: ED-108 published as interim MOPS in June 2001. Eurocae are presently progressing an update to ED-108 to form a full MOPS. SARPS: Published in November 2001. SARPS have recently been updated to enhance the point-to-point functionality offered by VDL4. AEEC: No activity ETSI have developed standards for VDL4 Ground Stations. The physical layer European Norm has been approved for publication. The link layer for broadcast functionality has passed through public enquiry and awaits completion of the public voting process.
Equipment Development	Pre-production equipment exists for both air and ground CNS have a type-certified VDL4 avionics, other manufacturers including SAAB have receivers, Rockwell-Collins are collaborating with SAAB to produce avionics. Additional development may be required for multi-channel operation. VDL4 (and its STDMA predecessor) has been integrated into various airframes, but Airbus and Boeing have not got firm plans for its inclusion in their airframes as standard equipment.
System Deployment	Sweden [271]and Russia [272] have significant deployment plans. Com4Solutions are planning a point-to-point network for AOC [273].
Conclusion	As a broadcast technology, VDL4 is rapidly reaching sufficient maturity for operational use. It is estimated that deployment could be widespread by 2006, but this is critically dependent on VHF frequency availability.

Table 6-2: VDL4 maturity assessment

6.2.2.3 The following table summarises the maturity of UAT.

Stage	Issues
System Development	The FAA have supported several UAT trials, including: Capstone Alaska, Operational Evaluations in Ohio Valley. In addition, Eurocontrol sponsored a trial of UAT.
Standards Development	MOPS: RTCA DO-282 was published 27th August 2002. No EUROCAE Activity. SARPS: AMCP WGW decided on 24th May 2002 that UAT SARPS should be developed. Historically the development of SARPS takes between 5 and 15 years. It is anticipated that UAT SARPS should be reasonably quick to develop and validate. It is estimated that the process will take 3 to 5 years. AEEC: No activity
Equipment Development	Trials Equipment Only Earliest Availability: 2006 No European manufacturers
System Deployment	FAA Plans No European Commitments
Conclusion	UAT promises to be a capable broadcast media. However, the lack of maturity in terms of standards development is a concern, as is the availability of a suitable frequency in Europe. It is estimated that UAT could not be considered for operational use in Europe before 2006, and it may be longer since it depends on several factors being resolved quickly: SARPs completion, frequency availability and equipment availability.

Table 6-3: UAT maturity assessment

6.2.2.4 The following table summarises the maturity of Mode S ES.

Stage	Issues
System Development	Mode S has been developed over the last 30 years and is a mature system. Current activity includes the Eurocontrol POEMS program which is developing pre-operational prototypes.
Standards Development	All standards work is complete
Equipment Development	Prototype POEMS ground stations are nearly available In response to the Mode S Elementary Surveillance mandate, and the expected Enhanced Surveillance mandate, Airbus and Boeing are certifying Mode S transponders with Elementary Surveillance, Enhanced Surveillance, and 1090 Extended Squitter ADS-B Out functions, along with the requisite aircraft installation wiring. Initial deliveries and service bulletins for in-service aircraft will start in the first quarter of 2003, in support of fleet wide compliance by 2005.
System Deployment	ECAC wide mandate planned for Mode S Elementary Surveillance; UK, France and Germany are likely to promulgate a mandate for Mode S Enhanced Surveillance.
Conclusion	Mode S ES has reached full maturity. Operational deployment could begin within 12 months and be widespread by 2006.

Table 6-4: Mode S ES maturity assessment

6.2.3 Complexity assessment

6.2.3.1 Table 6-5 summarises the key findings of the complexity assessment of the broadcast media.

Technology	Issues
1090 ES	Interaction with other 1090 systems is a concern. 1090 MHz is used for ground surveillance (SSR) and collision avoidance (ACAS). This leads to very high interference levels (eg FRUIT). It is predicted that the RF environment will saturate by 2015.
VDL4	Integration with other VHF systems causes difficulties, mostly relating to antenna positions. Eurocontrol are conducting architecture and interference studies. So far these indicate that VDL4 is no more of an issue than VDL2. The real issue is combining both in the same airframe.
UAT	No known integration problems Interference with/from DME infrastructure may be a concern in Europe,
Mode S ES	No additional concerns over those expressed for 1090 ES.

Table 6-5: Complexity assessment for broadcast technologies

6.2.4 Cost assessment

6.2.4.1 Table 6-6 summarises the ground costs for the broadcast technologies. The costs include the ground stations, but exclude the network and ATC centre upgrade costs which would be common to all technologies.

6.2.4.2 The non-recurring costs for Mode S Enhanced Surveillance are shown as zero, since no sensor upgrade costs were identified in the Eurocontrol ESDAP study [237], or the Revised Case for Mode S Enhanced Surveillance [23]. In those studies, significant network and ATC centre upgrade costs were identified for the upgrade to Mode S Enhanced Surveillance. These costs have been assumed here to apply generally to provision of ADD, over all technologies.

6.2.4.3 A detailed description of the approach used in deriving these costs is given in Annex C.

Costs in euro	**Mode S Enhanced Surveillance**	**1090 ES**	**UAT**	**VDL4 Broadcast**
Baseline assumed	Mode S Elementary Surveillance	Existing ground station site	Existing ground station site	Existing ground station site
Cost of ground station	0	75,000	75,000	140,000
Installation	0	15,000	15,000	28,000
Total initial cost per ground station (1 transceiver)	**0**	**90,000**	**90,000**	**168,000**
Yearly maintenance costs per ground station (1 transceiver)	0	7,500	7,500	14,000
Number of ground stations required in Europe	150	150	150	150
Total ground station costs (1 transceiver)	**0**	**13.5 million**	**13.5 million**	**25.2 million**

Table 6-6: Ground costs for the broadcast technologies

6.2.4.4 Tables 6-7 and 6-8 summarise the airborne costs for the broadcast technologies. A detailed description of the approach used in deriving these costs is given in Annex C.

Costs in euro	**Mode S Enhanced Surveillance**	**Mode S Enhanced Surveillance**	**1090 ES**	**1090 ES**
Baseline assumed	Mode S Elementary Surveillance. Transceiver & RCP not previously installed	Mode S Elementary Surveillance. Transceiver & RCP already installed.	Transceiver, RCP & CDTI not previously implemented	Transceiver & RCP already installed. CDTI not previously installed
Hardware				
Cost of transceiver	40,600 [Note 1]	n/a [Note 2]	40,600 [Note 3]	n/a [Note 4]
Radio control panel (x 2)	16,400 [Note 1]	n/a [Note 2]	16,400 [Note 3]	n/a [Note 4]
Antenna (x 2)	n/a	n/a	n/a	n/a
GPS antenna	n/a	n/a	1,500	1,500
CDTI (x 2)	n/a	n/a	68,000	68,000
Upgrade of CDTI	n/a	n/a	n/a	n/a
Upgrade of FMS	n/a	n/a	68,000	68,000
Integration, installation & certification				
Installation kit(s)	2,850	2,500 [Note 2]	9,725	2,500 [Note 4]
Service bulletin	5,700	n/a [Note 2]	19,450	n/a [Note 4]
Man-hours (80 euro/hour)	2,850	2,400 [Note 2]	9,725	2,400 [Note 4]
Operations & maintenance training				
Crew (6 crew) simulator training	n/a	n/a	77,000	77,000
Crew (6 crew) theoretical training	n/a	n/a	4,000	4,000
Simulator modification	n/a	n/a	8,000	8,000
Total initial costs per aircraft (1 transceiver)	**68,400**	**4,900**	**322,400**	**231,400**
Yearly maintenance costs per aircraft (1 transceiver)	5,700	n/a	19,450	13,750

Note 1: These figures assume a new transceiver and RCP are required. This will apply for a certain percentage of aircraft.

Note 2: These figures (from Airbus) assume a transceiver and RCP have already been installed in the upgrade to Elementary Surveillance. This will apply for a certain percentage of aircraft.

Note 3: These figures assume a new transceiver and RCP are required. This will apply for a certain percentage of aircraft.

Note 4: These figures (from Airbus) assume a transceiver and RCP have already been installed in the upgrade to Elementary or Enhanced Surveillance. This will apply for a certain percentage of aircraft.

Table 6-7: Airborne costs for the broadcast technologies (part 1)

Costs in euro	UAT	VDL4 Broadcast
Baseline assumed	CDTI previously installed	CDTI previously installed
Hardware		
Cost of transceiver	56,500	45,000
Radio control panel (x 2)	n/a	n/a
Antenna (x 2)	n/a	2,000
GPS antenna	1,500	1,500
CDTI (x 2)	n/a	n/a
Upgrade of CDTI	10,000	10,000
Upgrade of FMS	n/a	n/a
Integration, installation & certification		
Installation kit(s)	3,400	3,500
Service bulletin	6,800	7,000
Man-hours (80 euro/hour)	3,400	3,500
Operations & maintenance training		
Crew (6 crew) simulator training	n/a	n/a
Crew (6 crew) theoretical training	n/a	n/a
Simulator modification	n/a	n/a
Total initial costs per aircraft (1 transceiver)	**81,600**	**84,000**
Yearly maintenance costs per aircraft (1 transceiver)	6,800	7,000

Table 6-8: Airborne costs for the broadcast technologies (part 2)

6.2.5 Industrial assessment

6.2.5.1 Table 6-9 summarises the key findings of the industrial assessment of the broadcast media.

Technology	Issues
1090 ES	Significant support in US and Europe, all major manufacturers and airframes are working on 1090 solutions. Airbus are able to offer 1090 ES at the same time as Mode S ES in 2003, however ADS-B out is not anticipated until 2007.
VDL4	Significant support from some European States and Manufacturers. Europe has a significant advantage over the rest of the world in VDL4 technology, although some US manufacturers, eg ADSI, are interested including Rockwell Collins.
UAT	No European manufacturers.
Mode S ES	Mode S ES is supported by European industry, but is not supported by all aircraft operators, also support is lower in the non-Core states,

Table 6-9: Industrial assessment for broadcast technologies

6.2.6 Conclusions

6.3 ATM application support

6.3.1 Introduction

6.3.1.1 This section provides a comparison of the technologies ability to support the identified ATM applications. The analysis is presented by phase of flight.

6.3.1.2 Only an initial assessment is made. Since the publication of the TLAT report, significant work has been undertaken on each media, but no consolidated technical view has emerged. Our current understanding from those working in simulations and standardisation is that:

- UAT standards have been modified since TLAT and recent US simulations have shown it meeting all requirements in a core Europe 2015 scenario.
- 1090 ES meets TLAT requirements with a range up to 40 nm in a core Europe 2010 scenario. Simulations here have included a deployment of Mode S elementary surveillance, but not enhanced surveillance (which could reduce 1090 ES range). In lower density scenarios 1090 ES has a longer range.
- VDL4 meets medium-range TLAT range requirements but work is required on channel management to ensure that capacity requirements can be met. VDL4 can meet long-range requirements if sufficient VHF channels are made available, or in low-density scenarios.

6.3.1.3 VDL4 and UAT have been demonstrated to support the FIS-B requirements, 1090 ES does not appear to support these requirements (due to range and message content limitations).

6.3.2 Airport surface

6.3.2.1 The use of ADS-B on the airport surface is seen to offer early safety benefits. All three technologies have been demonstrated to some extent on the airport surface.

6.3.2.2 Multilateration systems offer a credible alternative to ADS-B for air-ground applications and are operational at a number of airports including Heathtrow.

6.3.2.3 Airport surface applications require less data (just SV report) but a much higher update rate (1 Hz is recommended) than airborne applications.

6.3.2.4 The number of vehicles to be supported is debated. MASPS require that 250 vehicles be supported (100 in motion and 150 fixed). However, the ADS-B applications like runway incursion monitoring would only require those vehicles authorised to enter the runway to be transmitting ADS-B messages. A much lower number would then need to be active at any one time. There are many non-critical vehicles on an airport and fitting them all with equipment certified to the same level as aircraft avionics would be prohibitively expensive. Low-cost fleet management systems can be implemented to monitor the location of these vehicles, and this is already the case at several airports.

6.3.2.5 A further consideration for the deployment of ADS-B at airports is the high levels of multi-path interference and shielding from buildings and other aircraft. A number of ground sensors will be required to support air-ground applications.

6.3.2.6 No simulations of surface applications were performed as part of the TLAT deliberations, however 1090 ES and UAT have been demonstrated in the airport environment with varying levels of success. 1090 ES can be used as part of a multilateration system.

6.3.2.7 VDL4 is able to provide the required 1 second update rate, but without slot re-use capacity would be limited to 75 vehicles per channel. The VDL4 sleep facility can be utilised to increase effective capacity.

6.3.2.8 With two local channels providing sufficient capacity for 150 vehicles this is likely to be sufficient for the vast majority of airports.

6.3.3 Terminal area

6.3.3.1 In order to support terminal area applications, the broadcast media would need to support an update rate of 5 seconds for up to 800 aircraft over a range of 20 to 60 nm.

6.3.3.2 Only UAT has been demonstrated (by simulation) to meet all these requirements in high-density areas such as Core Europe.

6.3.3.3 1090 ES is expected to able to support this update rate for ranges of 40 to 50 nm but not the full 60 nm for air-air applications. For air-ground applications the full range can be achieved using ground stations with sectored antennas. It is understood that performance of 1090 ES has been evaluated without enhanced surveillance; the inclusion of which would reduce the effective range due to increased FRUIT. Conversely, the performance of 1090 ES could be greatly enhanced by a significant rationalisation of the current and proposed SSR/Mode S ground infrastructure.

6.3.3.4 For 1090 ES and UAT, the high frequency used means that antenna blocking can occur even at short range. Therefore extensive flight trials of applications are recommended to support antenna sighting criteria.

6.3.3.5 VDL4 will need multiple channels to support these applications. The total number is not known but may be four. Channel management issues still need to be fully resolved and a successful channel management scheme needs to be devised.

6.3.4 En-route and transition

6.3.4.1 In order to support en-route applications, the broadcast media will need to support an update rate of 12 seconds of the State Vector for up to 1000 aircraft for 60 to 150 nm and additional intent information.

6.3.4.2 UAT has been demonstrated by simulation to meet these requirements.

6.3.4.3 1090 ES is unable to meet the range requirements for these applications.

6.3.4.4 To support these requirements VDL4 is expected to require two channels in addition to those identified previously.

6.3.5 Remote and oceanic

6.3.5.1 The key requirement for Remote and Oceanic applications is range rather than capacity. The basic position and velocity reports need to be augmented with intent data.

6.3.5.2 1090 ES has problems in supporting very long-range applications.

6.3.5.3 A further consideration for long-range applications is a potential need for point-to-point air-air datalink to ensure that both parties are aware of the proposed resolution strategy for a conflict. Only VDL4 supports a full-capability air-air datalink.

6.4 Roles in the datalink roadmap

6.4.1 Step 2: ATM applications related to downlink of air-derived data

6.4.1.1 There are three potential means of providing downlink of air derived data:

- CAP and SAP using a point-to-point media
- ADS-B in air-to-ground mode only
- Mode S ES

6.4.1.2 The use of CAP and SAP has been ruled out due to the scarcity of VHF spectrum. The UK, France and Germany are considering a mandate for Mode S ES in their airspace.

6.4.1.3 It has been previously noted that in their current state, the ADS-B media will only support basic air-ground surveillance.

6.4.1.4 Aircraft equipped to support the Mode S Elementary Surveillance mandate are also likely to meet the requirements for Mode S ES and 1090 ES. It is therefore recommended that this step be achieved using a combination of Mode S ES and 1090 ES, with regional implementation of VDL4 not ruled out.

6.4.2 Step 3: Introduction of spacing

6.4.2.1 Within Europe, the two potential candidates to support ASAS spacing applications are 1090 ES and VDL4. It is noted that the airborne cost of supporting this step is dominated by the CDTI and integration costs, not the media, however re-use of the TCAS receiver could provide a low cost option of 1090 ES but has certification and acceptability issues.

6.4.2.2 New aircraft equipped will be equipped with ADS-B and CDTI. These aircraft will be able to participate in air-air pair wise applications. The deployment of TIS-B ground stations could increase the likelihood of these aircraft being able to participate in such an application. Terminal and surface applications are the most likely to generate benefits.

6.4.2.3 Local/regional plans which support sufficient benefit for wider equipage. Such plans could include:

- Surface movement application
- Regional air-ground applications
- Regional air-air applications

6.4.2.4 Whilst 1090 ES is considered that most mature and support technology, particular ANSPs and Aircraft Operators could make local agreements to use the other technologies. In Europe it is particularly likely that local implementations of VDL4 will occur. VDL4 has a significant European ground infrastructure which has been deployed in NEAN and NUP programs. This infrastructure is being used to support a number of operational evaluations as part of the NUP2 project.

6.4.3 Step 4: Extension of a/g ATM applications

6.4.3.1 APP4b, extended uplink services, could be supported by FIS-B. 1090 ES is not suitable for this application. For VDL4, a comparative simulation is required to determine if this step is best achieved as a broadcast or addressed application.

6.4.4 Step 5a: Introduction of separation and self-separation

6.4.4.1 The successful use of ASAS separation and self-separation applications is central to the application roadmap in this timeframe. A dual link solution is required to achieve the high levels of availability and integrity required by these applications. The applications also require an air-air point-to-point datalink.

6.4.4.2 The potential solutions are:

- Combined use of 1090 ES and VDL4. Eurocontrol are currently investigating this solution.
- Combined use of 1090 ES and UAT extended to include an air-air point-to-point datalink; this could be by the adoption of simplified STDMA protocols within the UAT technology which could also provide more graceful degradation in high density airspace.
- Combined use of VDL4 and UAT.

6.4.4.3 It is noted that the latest results indicate that 1090 ES is not capable of supporting ADS-B in the traffic densities predicted for beyond 2010 in core Europe. In order to provide continued support for ADS-B applications using 1090 ES it will be necessary to reduce FRUIT by systematically improving the ground segment.

6.4.4.4 Beyond 2020, the requirements for broadcast and air-air communications in general are not clear. Potential aircraft densities could mean that all three technologies will be capacity limited.

6.4.4.5 It is also likely that the data broadcast will evolve with flight management computers and navigation sources. A more intent based form of free flight is attractive with information of where an aircraft intends to be at various times in the future being broadcast rather than current position.

6.4.4.6 It is therefore likely that a new technology will be required to support future requirements, and the potential of CDMA solutions should be investigated.

6.5 Conclusions

6.5.1 The following tables summarises the key points on each technology:

Technology	Points of Interest / Role in Datalink Roadmap
1090 ES	▪ Most mature of the proposed technologies with the earliest potential implementation date and possible widespread use by 2006. ▪ In support of the Mode S mandate, large airliners are being equipped with updated Mode S transponders from 2003, with fleet wide retrofit in 2005. These transponders also perform Mode S Enhanced Surveillance and 1090 ES functions. ▪ The air-air range of 1090 ES make it suitable for TMA applications but unsuitable for long-range applications. ▪ Implementation of 1090 ES would benefit from, and may even require, a concerted rationalisation of the SSR ground infrastructure. ▪ Further work on airborne and ground antenna siting criteria is required. ▪ An ‘ADS-out’ solution is the cheapest way to get ADS-B capability. The TCAS functionality can be used to display proximate traffic based on 1090 ES returns. However, the usefulness of this display is limited and a full CDTI or similar display will be needed for most air-air applications.

Technology	Points of Interest / Role in Datalink Roadmap
VDL4	▪ VDL4 is the most flexible of the proposed systems providing variable reporting rates and a wide range of intent data. ▪ VDL4 is able to provide other services such as ATN communications (recently standardised) and air-air point-to-point communications (it is the only link with an air-air data link). ▪ VDL4 has the best airport surface performance due to lower frequency of operation (it suffers fewer shielding problems). ▪ Airborne VHF interference issues are still being addressed by Airbus through the NUP programme. DSB-AM voice may be adversely affected by the operation of VDL4 on the same airframe. ▪ Deployment of VDL4 will require a concerted effort to free sufficient bandwidth in the congested VHF bands. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there will be no regulatory impediments against applying VDL Mode 4 as a data link supporting CNS applications. ▪ Work on a channel management plan, including identification of the number of VHF channels required, is critical and urgently required. ▪ Subject to frequency availability and channel management plan – which are serious constraints ▪ VDL4 could be start use by 2006.
UAT	▪ UAT has been selected by the FAA to support ADS-B on general aviation aircraft. ▪ Simulations show that UAT has the best range/capacity performance of the proposed systems with sufficient capacity for all applications including FIS-B and TIS-B. ▪ UAT does not support the requirements for long-range applications or transmission of all the required intent parameters. ▪ UAT does not support an air-air point-to-point datalink. ▪ UAT requires SARPs standardisation work which can be a very slow process. To avoid significant delays, SARPs standards should have minimum deviation from the existing MOPS published by RTCA. ▪ There is a serious concern about the European availability of a suitable frequency for UAT before 2006 and even well after this date. This is due to the additional 180-200 DMEs required in Europe to support the proposed RNP RNAV mandate. (See section 7.10.2 for a further discussion of the issue). ▪ UAT could not be considered for operational use in Europe before 2006, and it may be longer since it depends on several factors being resolved quickly: SARPs completion, frequency availability and equipment availability.

Table 10: Summary of broadcast media

6.5.2 Further investigations are needed (which are beyond the scope of this project), in particular full safety assessments of the proposed applications are required to verify integrity and availability assumptions.

6.5.3 In addition, detailed research should be conducted into:

- Possibilities to rationalise the SSR ground infrastructure to reduce interference to 1090 ES and therefore improve performance.
- Simulations of 1090 ES performance if Mode S enhanced surveillance is deployed (it will reduce 1090 ES range).
- VHF frequency availability and channel management plan for VDL4.
- Applicability of UAT to European airspace and in particular the availability of a suitable frequency.
- Multi-link architectures, particularly airborne interfaces that can support an early data link such as 1090 ES with another one being added later.

7 Scenario selection

7.1 Purpose

7.1.1 This section provides a multi-criteria analysis of potential technology scenarios. Each scenario represents a technology selection for each of the five steps in the roadmap. The following table is a reminder of the technology requirements for each step.

Step	Description	Technology Requirements	Candidates
1	Early a/g ATM applications.	This step requires the deployment of an initial air-ground datalink	VDL2 VDL4
2	ATM applications related to downlink of air-derived data.	Whilst this step could be achieved by the use of additional datalink applications, the lack of VHF frequencies has led to the recommendation that a downlink broadcast media is deployed.	Mode S ES 1090 ES VDL4
3	Introduction of spacing.	This step requires the deployment of ADS-B within the aircraft including processing and display capabilities. It could be supported by the use of TIS-B.	1090 ES VDL4
4	Extension of a/g ATM applications.	This step involves additional use of the air-ground datalink, it could involve the deployment of a new technology or just additional frequencies.	VDL2 VDL4 VDL3
5a	Introduction of separation and self-separation.	Dual-link ADS-B solution including a point-to-point air-air capability.	1090 ES and VDL4 1090 ES and E-UAT VDL4 and UAT
5b	Introduction of conflict free trajectory negotiation	Enhanced air-ground datalink supporting low transit delays and high capacity	3G SDLS

Table 7-1: Technology steps in the datalink roadmap

7.1.2 The potential scenarios considered are defined in Table 7-2.

7.1.3 The technologies listed in each step represent new technologies. In all cases the previous technologies are not removed – the requirements for Step 5b are not clear, but it may be that previous technologies can be decommissioned when ‘newcon’ is fully deployed.

7.1.4 Where none is listed, the previous technology is still available, so in Scenario A, VDL2 is deployed in Step 1 and used to support Step 4.

Step / Scenario	1	2	3	4	5a	5b
A	VDL2	Mode S ES (1090 ES)	1090 ES	None	VDL4	Newcom
B	VDL2	Mode S ES (1090 ES)	1090 ES	None	UAT	Newcom
C	VDL2	Mode S ES (1090 ES)	1090 ES	None	None	Newcom
D	VDL4	VDL4	VDL4	None	UAT	Newcom
E	VDL2 or VDL4	Mode S ES (1090 ES) or VDL4	1090 ES or VDL4	None	VDL4 or 1090 ES	Newcom
F	VDL2 or VDL4	Mode S ES (1090 ES) or VDL4	1090 ES or VDL4	None	UAT	Newcom
G	VDL2	Mode S ES (1090 ES)	1090 ES	VDL4	VDL4	Newcom
H	VDL2	Mode S ES (1090 ES)	1090 ES	VDL3	UAT	Newcom

Table 7-2: Potential scenarios

7.1.5 The eight scenarios selected include those considered by the consortium on the evidence gathered during the technology assessment to offer the most likely, the cheapest, and most beneficial roadmaps. Limited alternatives have also been included for comparison.

7.1.6 In each case a description of the steps, including any limitations, is followed by a scoring table as explained in 3.3. Score are from 0 to 5 with 5 representing a high score. The costs used to score the scenarios are presented in Annex C.

7.1.7 In all scenarios, 'Newcom' is assumed for step 5b. 'Newcom' represents the next generation of system and is likely to be a hybrid terrestrial/satellite 3G/CDMA system. Costs for 'Newcom' are not included.

NOTE: Some comments on scoring were received during the Public Consultation Process, principally from Airbus and Easy Jet. These comments have not been included as they were not consistent. As the general conclusion of the study is that further work needs to done before the final technology selection is made it was not felt appropriate or possible to resolve these differences at this stage.

7.2 Scenario A

7.2.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2015	2015	2015
Technologies	VDL2	Mode S ES 1090 ES	1090 ES	None	VDL4	Newcom

Table 7-3: Summary of scenario A

7.2.1.1 This scenario includes the following steps:

- Step 1:
  - VDL2 is deployed first for AOC and then for ATN.
  - This step will require at least 6 frequencies by 2010 (excluding those used for AOC).
- Step 2:
  - Mode S ES is used for Air Derived Data in Core Europe
  - 1090 ES is used for ADS-B (out) for Air Derived Data in non-core areas and as a gap filler in core areas.
- Step 3:
  - 1090 ES is used for ADS-B (in) supporting ATSAW and spacing applications.
  - Interference, in particular the high FRUIT rate means that 1090 ES will not support the range requirements for spacing applications much beyond 2010.
- Step 4:
  - VDL2 is continued to be used for ATN communications, the additional load requiring additional frequencies. It is anticipated that Step 4 will have to be delayed until the next generation of communications is available.
- Step 5:
  - VDL4 is used to enhance the ADS-B service to support separation and self-separation applications.
  - A ‘new technology’ is deployed to support 4D trajectory negotiation. At present it is believed that 3G, both terrestrial and satellite, offers the best opportunity.

7.2.2 Scoring

Criteria	Score (Max = 5)	Rationale
Benefits	4	High score as the vast majority of the benefits are delivered, however, Step 4 benefits are delayed until Step 5 due to lack of frequencies.
Costs	3	Technology specific costs are € 18.3 Bn.
Frequency Availability	3	At least 6 VDL2 frequencies are required for Step 1 by 2010. At least 4 VDL4 frequencies are required for Step 5a; co-ordination with the navigation band may be possible in this timeframe.
Global Interoperability	3	Medium score, although VDL2 and 1090 ES are compatible with FAA plans, this route is not compatible with the FAA NEXCOM program (VDL3).
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	2	VDL2 has support for early AOC but this will be limited by the available frequencies.

Table 7-4: Scoring for scenario A

7.3 Scenario B

7.3.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2015	2015	2015
Technologies	VDL2	Mode S ES 1090 ES	1090 ES	None	UAT	newcom

Table 7-5: Summary of scenario B

7.3.1.1 This scenario is the same as scenario A, except that in Step 5a, UAT is used to augment 1090 ES instead of VDL4.

7.3.1.2 An enhancement to UAT will be required to support air-air point-to-point communications for self-separation. Development of this system may delay Step 5a.

7.3.2 Scoring

7.3.1 Table 7-6 provides the scoring for scenario B.

Criteria	Score (Max = 5)	Rationale
Benefits	4	High score as the vast majority of the benefits are delivered, however, Step 4 benefits are delayed until Step 5 due to lack of frequencies.
Costs	4	Technology specific costs are € 16.8 Bn.
Frequency Availability	2	At least 6 VDL2 frequencies are required for Step 1 by 2010. A frequency is required for UAT. Given ECAC plans to extend the number of DMEs by 180 to 200 by 2010 there is doubt that co-ordination with the navigation band is possible in this timeframe.
Global Interoperability	3	Although VDL2 and 1090 ES are compatible with FAA plans, this route is not compatible with the FAA NEXCOM program (VDL3) or the regional plans in ECAC (VDL4). Although the FAA support UAT this is for GA use only.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	2	VDL2 has support for early AOC but this will be limited by the available frequencies.

Table 7-6: Scoring for scenario B

7.4 Scenario C

7.4.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2015	2015	2015
Technologies	VDL2	Mode S ES 1090 ES	1090 ES	None	Newcom	

Table 7-7: Summary of scenario C

7.4.1.1 This scenario is the same as scenario A, except that 'Newcom' is used to support both Steps 5a and 5b.

7.4.1.2 There is no firm date for the availability of 'Newcom'.

7.4.1.3 This scenario contains serious risk. If the 'Newcom' technology is not available in time, all services on VDL2 and 1090 ES would be compromised.

7.4.1.4 The saturation of VDL2 will occur when the traffic density reaches a point where insufficient VHF frequencies can be made available to provide datalink communications. The date at which VHF saturation will occur is not yet known as it depends on the demand for voice frequencies.

7.4.1.5 According to the TLAT results, 1090 ES will saturate some time between 2010 and 2015. As traffic density increases, the effective range of 1090 ES reduces. If the range falls below 14NM this will also impact on the ability of TCAS to function correctly.

7.4.1.6 It seems prudent to have options available to prevent either occurring.

7.4.2 Scoring

7.4.1 Table 7-6 provides the scoring for scenario B.

Criteria	Score (Max = 5)	Rationale
Benefits	3	Medium score, there is substantial doubt in this scenario's ability to support the Application Roadmap in the 2010-2015 period.
Costs	5	Technology specific costs are € 15.1 Bn.
Frequency Availability	4	At least 6 VDL2 frequencies are required for Step 1 by 2010.
Global Interoperability	3	VDL2 and 1090 ES are compatible with FAA plans. Whilst this route is not compatible with the FAA NEXCOM program (VDL3) or the regional plans in ECAC (VDL4).
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	2	VDL2 has support for early AOC but this will be limited by the available frequencies.

Table 7-8: Scoring for scenario C

7.5 Scenario D

7.5.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2008	2008	2010	2010	2015	2015
Technologies	VDL4	VDL4	VDL4	None	UAT	Newcom

Table 7-9: Summary of scenario D

7.5.1.1 This scenario represents a route dominated by VDL4. Although it has regional support in parts of Europe, it is does not have widespread support and places a high burden on the VHF band.

- Step 1:
  - VDL4 is deployed first for ATS communications. Current VDL2/AOC plans would not be affected. Step 1 would be delayed by the need to resolve remaining VDL4 issues.
- Step 2:
  - VDL4 is used in broadcast mode to support Air Derived Data. This requires a mandate to ensure the benefits are realised.
  - A Mode S Enhanced Surveillance mandate is not needed, Mode S elementary surveillance is supported in Core Europe.
- Step 3:
  - VDL4 is used for ADS-B (in) supporting ATSAW and spacing applications. This requires sufficient frequencies to be made available, including significant coordination with the navigation band. It is noted that decommissioning of VORs is possible in this timeframe which would free up the required VHF spectrum if co-ordination with the navigation domain were achieved. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there will be no regulatory impediments against applying VDL Mode 4 as a data link supporting CNS applications.
- Step 4:
  - VDL4 is continued to be used for ATN communications, the additional load requires one additional frequency which does not delay the benefits.
- Step 5:
  - UAT is used to enhance the ADS-B service to support separation and self-separation applications
  - A ‘new technology’ is deployed to support 4D trajectory negotiation.

7.5.2 Scoring

7.5.1 Table 7-6 provides the scoring for scenario D.

Criteria	Score (Max = 5)	Rationale
Benefits	3	This scenario scores lowly as steps 1 and 2would be delayed in comparison to scenario A and B, there is also doubt over the ability of VDL4 to support ADS-B in core Europe. Whilst this is largely a capacity issue, sufficient channel management procedures have not yet been demonstrated and a VDL4 only ADS-B solution is considered a technical risk.
Costs	5	Technology specific costs are € 14.5 Bn.
Frequency Availability	2	Low score as significant action is required to co-ordinate VDL4 use of the navigation band for ADS-B. However, overall less VHF spectrum is used than VDL2 only options.
Global Interoperability	1	Low score as there is limited interoperability with US and non-European plans, and 1090 TIS-B may be required to support US carriers.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	3	Use of VDL4 for ATS would allow more spectrum for VDL2 supporting AOC. Some operators could also chose to use VDL4 for AOC.

Table 7-10: Scoring for scenario D

7.6 Scenario E

7.6.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2010	2015	2015
Technologies	VDL2 or VDL4	Mode S ES 1090 ES or VDL4	1090 ES or VDL4	None	1090 ES and VDL4	Newcom

Table 7-11: Summary of scenario E

7.6.1.1 This scenario represents a combination of scenarios A and D. Two different aircraft equipages are supported by dual ground systems as summarised in Table 7-12.

Step	Aircraft A	Aircraft B	Ground
1	VDL2/ATN Upgrade	VDL4 palette supporting AOC, ATN and ADS-B	VDL2 and VDL4 ground stations
2	Support for Mode S ES mandate	Support for Mode S ES mandate	Mode ES ground Stations
3	Upgrade to support ADS-B (in) via 1090 ES including CDTI	VDL 4 palette enhancement to enable CDTI applications (potentially zero cost)	VDL4 surveillance ground stations TIS-B needs to be supported for both 1090 ES and VDL4
4	CMU/ATSU enhancement for new applications	VDL4 palette enhancement for new applications	ATC centre enhancements for new applications
5	VDL4 as complimentary broadcast media	1090 ES as complimentary broadcast media	

Table 7-12: Scenario E equipage routes

7.6.1.2 The steps have the following consequences:

- Step 1:
  - Both VDL2 and VDL4 are deployed first for AOC and then for ATN. Aircraft operators are able to choose between the traditional AOC suppliers and new entrants supporting VDL4 in Europe. It is unlikely that VDL4 will be supported globally, so operators working outside ECAC are expected to follow the VDL2 route, as will the majority of Airbus and Boeing customers who are able to take advantage of low cost VDL2 upgrades to their existing ACARS equipment.
- Step 2:
  - Mode S ES is used for Air Derived Data in Core Europe
  - 1090 ES is used for ADS-B (out) for Air Derived Data in non-core areas and as a gap filler in core areas.

- Step 3:
  - Both 1090 ES and VDL4 are used for ADS-B (in) supporting ATSAW and spacing applications. Ground systems supply a cross-link TIS-B solution.
- Step 4:
  - VDL2 and VDL4 continue to be used for ATN communications, the additional load required additional frequencies, but the extra capacity of VDL4 means that fewer frequencies are required and the benefits are not delayed.
- Step 5:
  - UAT is used to enhance the ADS-B service to support separation and self-separation applications
  - A 'new technology' is deployed to support 4D trajectory negotiation.

7.6.1.2 Scoring

7.6.1 Table 7-6 provides the scoring for scenario E.

Criteria	Score (Max = 5)	Rationale
Benefits	5	This scenario is able to deliver all the benefits identified
Costs	5	Technology specific costs are € 15.9 Bn.
Frequency Availability	3	Significant action is required to co-ordinate VDL4 use of the navigation band for ADS-B, but overall less VHF spectrum is used than only VDL2 options.
Global Interoperability	3	Limited interoperability with US plans, and 1090 TIS-B may be required to support US carriers.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	4	Both VDL2 and VDL4 are able to offer an AOC service.

Table 7-13: Scoring for scenario E

7.7 Scenario F

7.7.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2010	2015	2015
Technologies	VDL2 or VDL4	Mode S ES 1090 ES or VDL4	1090 ES or VDL4	None	UAT	Newcom

Table 7-14: Summary of scenario F

7.7.1.1 This scenario is a variant of scenario E in which UAT is deployed to support the introduction of separation and self-separation in Step 5a. This adds significantly to the costs, as all aircraft will need to equip with UAT, and to the frequency availability issues as available DME frequencies are scarce in Europe.

7.7.2 Scoring

7.7.2.1 Table 7-6 provides the scoring for scenario F.

Criteria	Score (Max = 5)	Rationale
Benefits	5	This scenario is able to deliver all the benefits identified
Costs	4	Technology specific costs are € 16.7 Bn.
Frequency Availability	2	Significant action is required to co-ordinate VDL4 use of the navigation band for ADS-B, but overall less VHF spectrum is used than only VDL2 options. A frequency is required for UAT. Given ECAC plans to extend the number of DMEs by 180 to 200 by 2010 there is doubt that co-ordination with the navigation band is possible in this timeframe.
Global Interoperability	3	Limited interoperability with US plans, and 1090 TIS-B may be required to support US carriers.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	3	Both VDL2 and VDL4 are able to offer an AOC service.

Table 7-15: Scoring for scenario F

7.8 Scenario G

7.8.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2010	2015	2015
Technologies	VDL2	Mode S ES 1090 ES	1090 ES	VDL4	VDL4	Newcom

Table 7-16: Summary of scenario G

7.8.1.1 This scenario sees the deployment of VDL4 to support both Step 4 and Step 5a. This scenario is compatible with the Eurocontrol Communications and Surveillance strategies, although both roles for VDL4 require further investigation.

7.8.1.2 This scenario could represent a planned response to the risks inherent in Scenario C. That is by continuing the work needed to deploy VDL4, the community would be in a position to react if the promise of 'Newcom' is not available early enough to ensure continued operations of datalink applications or broadcast applications.

7.8.2 Scoring

7.8.1 Table 7-6 provides the scoring for scenario G.

Criteria	Score (Max = 5)	Rationale
Benefits	5	This scenario is able to deliver all the benefits identified
Costs	2	Technology specific costs are € 18.9 Bn.
Frequency Availability	2	VHF frequencies would be required for VDL4 for both surveillance and communications functions. This would place a strain on the VHF spectrum and require use of the Navigation band currently used for VORs which are expected to be decommissioned by 2010.
Global Interoperability	3	Limited interoperability with US plans, and 1090 TIS-B may be required to support US carriers.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	4	VDL2 is able to offer an AOC service.

Table 7-17: Scoring for scenario G

7.9 Scenario H

7.9.1 Description

Step	1	2	3	4	5a	5b
Timeframe	2005	2005	2010	2010	2015	2015
Technologies	VDL2	Mode S ES 1090 ES	1090 ES	VDL3	UAT	Newcom

Table 7-18: Summary of scenario H

7.9.1.1 This scenario represents a variant of scenario B in which VDL3 is deployed to support Step 4.

7.9.1.2 In Europe it is anticipated that VDL3 would be deployed as a wide area data-only network (the 3T mode) rather than as a combined voice/data network (the 3V1D) mode planned by the FAA.

7.9.1.3 This scenario would provide a high level of interoperability with the US.

7.9.2 Scoring

7.9.1 Table 7-6 provides the scoring for scenario H.

Criteria	Score (Max = 5)	Rationale
Benefits	5	This scenario is able to deliver all the benefits identified
Costs	2	Technology specific costs are € 19 Bn.
Frequency Availability	1	Introduction of VDL3 in 3T mode has similar level of difficulty as introduction of VDL4. A frequency is required for UAT. Given ECAC plans to extend the number of DMEs by 180 to 200 by 2010 there is doubt that co-ordination with the navigation band is possible in this timeframe.
Global Interoperability	4	Limited interoperability with US plans, and 1090 TIS-B may be required to support US carriers.
Voice Communications	1	Low score as additional voice capacity is not supported until step 5b. An additional voice only technology could be required in addition to 8.33 expansion plans by 2010.
Non-ATC Data Comms	4	VDL3 would provide greater capacity for an AOC service.

Table 7-19: Scoring for scenario H

7.10 Conclusion

7.10.1 Table 7-20 summarises the scoring for the potential scenarios.

	Weight	A	B	C	D	E	F	G	H
Benefits	6	4	4	3	3	5	5	5	5
Costs	5	3	4	5	5	5	4	2	2
Frequency Availability	4	3	2	4	2	3	2	2	1
Global Interoperability	2	3	3	3	1	3	3	3	4
Voice Communications	2	1	1	1	1	1	1	1	1
Non-ATC Data Comms	1	2	2	2	3	4	4	4	4
Total (Weighted)	100	**61**	**62**	**69**	**58**	**79**	**70**	**60**	**58**

Table 7-20: Scenario scoring summary

7.10.2 The following notes assist in the interpretation of Table 7-20:

- 3 scenarios (C, D and E) represent the lowest cost. The scoring system assigned a score of 5 to the scenarios which came within 10% of the lowest cost solution. In the analysis, there was little cost differentiation between a route based on VDL2/Mode S EHS/1090 and one based on VDL4. The VDL4 route was marginally lower cost. The combination of scenarios C and D in steps 1, 2 and 3 to produce scenario E add costs associated with duplication of ground infrastructure. However, the increase in cost remains within 10% of the lower cost option – hence this scenario also scores 5. Scenarios G and H score poorly on costs because they involve an extra (or earlier) equipage stage for step 4.
- For benefits, scenarios C and D both scored poorly: C because it is unable to meet the requirements in steps 4 and 5a, D, based on VDL4, because it results in a delay to start of the roadmap.
- For spectrum efficiency, VDL2 only solutions have been given a higher score on the basis that an initial spectrum allocation has already been made. Note that solutions requiring two VDL links score poorly.
- For global interoperability, VDL4 solutions score poorly since there is no acceptance of VDL4 within the US. Conversely, solutions based on VDL3 and UAT score more highly on the basis that these correspond to current plans within the US.
- For voice communications, all solutions score 1 since it is assumed that, over the timescale of the roadmap, Europe will follow an 8.33kHz path.
- Non-ATC communication scoring is assigned on the basis of the data efficiency of the proposed solutions.

7.10.3 The multi-criteria analysis concentrates on a technical comparison of the scenarios. Scenario selection needs to also consider the level of consensus achieved by the scenarios. This is considered in the Datalink Roadmap document.

8 Conclusions

8.1 Considered technologies

8.1.1 Table 8-1 summarises the services supported by technologies which have been considered in this report.

Group	Technology	Air-Ground Datalink	Air-Air Datalink	Air-Air Broadcast	Uplink Broadcast	Downlink Broadcast	Annex
Baseline Technologies	AVPAC	✓					-
	HFDL	✓					D
	AMSS	✓					E
Significant Decisions	VDL2	✓			✓		F
	1090 ES			✓	✓	✓	G
	Mode S				✓	✓	H
Emerging Technologies	VDL3	✓					I
	VDL4	✓	✓	✓	✓	✓	J
	UAT			✓	✓	✓	K
	Gatelink	Airport Only					L
Future Technologies	NGSS	✓					M
	SDLS	✓			✓		N
	3G/UMTS	✓	✓	✓	✓	✓	O
	Boeing CS	✓					P

Table 8-1: Summary data link technology characteristics

8.2 Assessment of point-to-point technologies

8.2.1 The following table summarises the key points made about each point-to-point technology during the assessment.

Technology	Points of Interest / Role in Datalink Roadmap
HFDL	▪ The existing HFDL is the only current system capable of covering north polar routes. ▪ HFDL is hindered by very low data rates, but does support basic FANS1/A type applications and ACARS (ARINC). ▪ HFDL is retained in the roadmap for current use; but with long term replacement by future satcom possible.

Technology	Points of Interest / Role in Datalink Roadmap
AMSS	▪ AMSS is an existing system capable of providing narrow band data (throughput is approximately equal to VHF but transfer delay is much longer). ▪ Currently AMSS is used to support FANS1/A but also includes an ATN sub-network. ▪ AMSS is fitted to 2000+ mainly long haul aircraft. ▪ AMSS is hindered by high cost for avionics and communications charges. The price per kilobit could be lower if the system was used more. ▪ Retained for current use; replacement by future satcom is likely. Consideration of ATS use for Inmarsat-4 and Inmarsat-5 services is urgently required.
VDL2	▪ Significant deployment plans for VDL2/AOA and VDL2/ATN within the Link2000+ and FAA CBDLC/Build 1 programmes ▪ The effective data rate for VDL2 is of order 3000 bps for en-route airspace (see technology assessment document P167D2020 Section 5 and Annex F for a discussion of this data rate). ▪ VDL2/ATN is the first continental ATC datalink, but will require up to 9 operational channels by 2010. ▪ More details flight trials results are on-going to measure effectively how far VDL2 can correctly support CPDLC demanding applications (in PETAL II report, 95 % end-to-end dialogue time is 80 seconds for CPDLC). Flight trials results should confirm whether delivery of conflict-free trajectories be supported by VDL2. It is unlikely due to the required volume of information e.g., COTRAC). ▪ Due to the lack of deterministic-QoS and priority mechanisms, VDL2/ATN does not support long term goal of tactical datalinks. ▪ Supported for use as VDL2/AOA and VDL2/ATN for ATC.
VDL3	▪ Significant support in US where VDL3 is expected to be the next generation technology for both ATS voice and data. AOC data would remain on VDL2 ▪ Subject to meeting NARC Criteria, VDL3 is expected to be initially deployed to provide digitised voice for high altitude en-route airspace in the 2009 timeframe. ▪ The FAA does not expect to introduced VDL3 for data until around 2012 ▪ No support in Europe where 8.33 kHz voice is being implemented to redress shortage of voice channels; Europe does not have a long term strategy for voice. ▪ The combined voice and data makes VDL3 an attractive option for future deployment in the US; particularly as an ANSP replacing it’s voice infrastructure will effectively be deploying a datalink infrastructure. ▪ If deployed in Europe, VDL3 would have to be deployed as a wide area data-link (3T-mode).

Technology	Points of Interest / Role in Datalink Roadmap
VDL4	▪ VDL4 has only just been standardised for point-to-point communications, the DLS protocols were accepted by AMCP/8 as validated subject to flight trials. ▪ Maturity of avionics and ground stations is supported by the maturity of products for broadcast services. ▪ Integration of VDL4 onto a airframe already supporting VHF voice and VDL2 is still an issue. ▪ The effective data rate for VDL4 is 14 kbps (see technology assessment document P167D2020 Annex J for a discussion of this data rate) ▪ VDL4 is suited to the provision of an AOC communications for Regional and General Aviation operators who have not yet invested in ACARS. This is because fleet management applications are a natural consequence of the exchange of position in the system messages.
Gatelink	▪ A number of technologies have been proposed over the years for providing very high bandwidth communications for parked aircraft. The majority of the communications does not relate to ATC, although some clearances, including advanced slot management applications could be supported. ▪ Gatelink is an important enabler of Collaborative Decision Making (CDM). ▪ A European decision for a particular technology could support lower prices in the long term.
NGSS	▪ A number of potential NGSS, including Iridium, ICO and Globalstar, have been proposed over the years. These systems have their roots in mass personal communications. Only Iridium is still hopeful of providing an aeronautical service and is currently used for voice services by General Aviation in the US. ▪ The continued operational and financial difficulties of NGSS operators (due to the failure of their core non-aviation market) make them unattractive for commercial aviation. ▪ Current systems (ICO, Iridium and Globalstar) are not retained for inclusion in the roadmap. ▪ Future NGSS could be an important part of the aeronautical communications infrastructure.
SDLS	▪ SDLS is a research project sponsored by ESA ▪ Eurocontrol are developing a program called NexSat which reuses certain aspects of the SDLS programme. ▪ The design brief is to replicate VHF communications (voice and data) using a geo-stationary satellite. ▪ In its first guise, it would reuse existing Inmarsat infrastructure but use CDMA to improve services.
Boeing CS	▪ Broadband system capable of live TV to aircraft but has not been proposed for safety services. ▪ Not retained for inclusion in the roadmap

Technology	Points of Interest / Role in Datalink Roadmap
3G	▪ The aeronautical application of 3G is being researched by Eurocontrol, and the potential to offer significant advantages over VHF communications. ▪ Retained for use in Step 3. Significant research should be conducted into the best way of using 3G for aviation. This research should include security concerns of the use of a single channel to support all aircraft communications needs.

Table 8-2: Summary of Point-to-point technologies

8.3 Assessment of broadcast technologies

8.3.1 The key results of the technology assessment for broadcast media are summarised below.

Technology	Points of Interest / Role in Datalink Roadmap
1090 ES	▪ Most mature of the proposed technologies with the earliest potential implementation date and possible widespread use by 2006. ▪ In support of the Mode S mandate, large airliners are being equipped with updated Mode S transponders from 2003, with fleet wide retrofit in 2005. These transponders also perform Mode S Enhanced Surveillance and 1090 ES functions. ▪ The air-air range of 1090 ES make it suitable for TMA applications but unsuitable for long-range applications. ▪ Implementation of 1090 ES would benefit from, and may even require, a concerted rationalisation of the SSR ground infrastructure. ▪ Further work on airborne and ground antenna siting criteria is required. An ‘ADS-out’ solution is the cheapest way to get ADS-B capability. The TCAS functionality can be used to display proximate traffic based on 1090 ES returns. However, the usefulness of this display is limited and a full CDTI or similar display will be needed for most air-air applications.

Technology	Points of Interest / Role in Datalink Roadmap
VDL4	▪ VDL4 is the most flexible of the proposed systems providing variable reporting rates and a wide range of intent data. ▪ VDL4 is able to provide other services such as ATN communications (recently standardised) and air-air point-to-point communications (it is the only link with an air-air data link). ▪ VDL4 has the best airport surface performance due to lower frequency of operation (it suffers fewer shielding problems). ▪ Airborne VHF interference issues are still being addressed by Airbus through the NUP programme. DSB-AM voice may be adversely affected by the operation of VDL4 on the same airframe. ▪ Deployment of VDL4 will require a concerted effort to free sufficient bandwidth in the congested VHF bands. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there will be no regulatory impediments against applying VDL Mode 4 as a data link supporting CNS applications. ▪ Work on a channel management plan, including identification of the number of VHF channels required, is critical and urgently required. ▪ Subject to frequency availability and channel management plan – which are serious constraints ▪ VDL4 could be in use by 2006.
UAT	▪ UAT has been selected by the FAA to support ADS-B on general aviation aircraft. ▪ Simulations show that UAT has the best range/capacity performance of the proposed systems with sufficient capacity for all applications including FIS-B and TIS-B. ▪ UAT does not support the requirements for long-range applications or transmission of all the required intent parameters. ▪ UAT does not support an air-air point-to-point datalink. ▪ UAT requires SARPs standardisation work which can be a very slow process. To avoid significant delays, SARPs standards should have minimum deviation from the existing MOPS published by RTCA. ▪ There is a serious concern about the European availability of a suitable frequency for UAT before 2006 and even well after this date. This is due to the additional 180-200 DMEs required in Europe to support the proposed RNP RNAV mandate. (See section 7.10.2 for a further discussion of the issue). ▪ UAT could not be considered for operational use in Europe before 2006, and it may be longer since it depends on several factors being resolved quickly: SARPs completion, frequency availability and equipment availability.

Table 8-3: Summary of broadcast technologies

8.4 Recommendations

8.4.1 The following recommendations have been made during this report concerning point-to-point media:

- Detailed fast-time simulations are required of VDL2 and VDL4 to determine the effective data rate under representative load conditions.
- Frequency planning criteria need to be developed for VDL3 and VDL4.
- Airborne architecture criteria need to be established for all VDLs.
- The specification of DSB-AM voice radios need to be re-visited to establish if interference criteria can be strengthened.

8.4.2 The following recommendations have been made during this report concerning broadcast media:

- Further investigations are needed (which are beyond the scope of this project), in particular full safety assessments of the proposed applications are required to verify integrity and availability assumptions.
- Possibilities to rationalise the SSR ground infrastructure to reduce interference to 1090 ES and therefore improve performance need to be investigated.
- Simulations of 1090 ES performance if Mode S enhanced surveillance is deployed (it will reduce 1090 ES range) are required to assess impact.
- Research in VHF frequency availability and channel management plan for VDL4.
- Applicability of UAT to European airspace and in particular the availability of a suitable frequency needs further consideration.
- Multi-link architectures, particularly airborne interfaces that can support an early data link such as 1090 ES with another one being added later need to be researched.

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9 Abbreviations and acronyms

1090 ES	1090 Extended Squitter
ACARS	Aircraft Communications Addressing and Reporting System
ACL	ATC Clearance Message
ACM	ATC Communication Management
ADAP	Automated Downlink of Airborne Parameters
ADD	Air Derived Data
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
AEEC	Airline Electrical Equipment Committee
AGL	Above Ground Level
AIC	Aeronautical Information Circular
AMSS	Aeronautical Mobile Satellite Service
AOC	ACARS over AVLC
AOC	Aeronautical Operational Communications (or Control)
APC	Air Passenger Communications
ARINC	Aeronautical Radio, Inc
ARNS	Aeronautical Radio-Navigation Service
ARV	Air Reference Velocity
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
ATSAW	Airborne Situational Awareness
AVPAC	Aviation Packet Radio
AVLC	Aviation Link Control
BDS	Binary Data Store
BIS	Boundary Intermediate System
CAA	Cargo Airline Association (US)
CAA	Civil Aviation Authority (UK)
CAP	Controller Access Parameters
CDMA	Code Division Multiple Access
CDTI	Cockpit Display of Traffic Information
COTRAC	Common Trajectory Coordination
CPDLC	Controller Pilot Data Link Communications

CMU	Communications Management Unit
CRC	Cyclic Redundancy Check
CSP	Communications Service Provider
CWP	Controller Work Position
D-ATIS	Digital-Automated Traffic Information Service
DGPS	Differential Global Position System
D/L	Data Link
DLIC	Data Link Initiation Capability
DME	Distance Measuring Equipment
D-FIS	Digital – Flight Information Service
D-OTIS	Datalink – Operational Terminal Information Service
D-RVR	Datalink – Runway Visual Range
DSC	Downstream Clearance
D-SIGMET	Digital – Significant Meteorological
DYNAV	Dynamic Route Availability
ECAC	European Civil Aviation Conference
ETSI	European Telecommunications Standards Institute
EUP	Effective Update Rate
EVA	Enhanced Visual Acquisition
FAA	Federal Aviation Authority
FANS	Future Air Navigation System
FDP	Flight Data Processor
FEC	Forward Error Correction
FIS-B	Flight Information Service – Broadcast
FLIPCY	Flight Plan Consistency
FLIPINT	Flight Plan Intent
FMS	Flight Management System
FOM	Figure Of Merit
FRUIT	Friendly Replies Unsynchronised in Time.
GA	General Aviation
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSC	Global Signalling Channel
HFDL	High Frequency Data Link
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFE	In Flight Entertainment

ITU	International Telecommunications Union
JAFTI	JURG ADS-B Fast Track Initiative
JTIDS	Joint Tactical Information Distribution System
JURG	Joint IATA/AEA CNS/ATM User Requirements Group
KHz	Kilohertz
LAN	Local Area Network
MASPS	Minimum Aviation System Performance Standards
METAR	Meteorological Aviation Routine Weather Report
MIDS	Multifunction Information Distribution System
Mode S ES	Mode Select Enhanced Surveillance
MOPS	Minimum Operational Performance Specification
MS	Mode Status
MSSS	Mode S Specific Services
NEXCOM	Next Communications (FAA)
NGSS	Next Generation Satellite System
NOTAM	Notice to Airmen
Nm	Nautical mile
PPD	Pilot Preferences Downlink
QoS	Quality of Service
R&D	Research and Development
RDP	Radar Data Processing
RF	Radio Frequency
RSC	Regional Signalling Channel
RTD	Research and Technological Development
SARPS	Standards and Recommended Practices
SAP	System Access Parameters
SC	Status Change
SDLS	Satellite Data Link System
SIEM	SSR/IFF Environment Model
SITA	Société Internationale de Télécommunications Aéronautiques
SNOWTAM	Snow NOTAM
SSR	Secondary Surveillance Radar
STDMA	Self-Organising TDMA
SV	State Vector
TC	Trajectory Change
TCAS	Traffic Alert and Collision Avoidance System
TCP	Trajectory Change Point
TDMA	Time Division Multiple Access

TIS-B	Traffic Information Service – Broadcast
TLA	Three Letter Acronym
TLAT	Technical Link Assessment Team
TS	Target State
UAT	Universal Access Transponder
UMTS	Universal Mobile Telecommunications System
US	United States
UTC	Universal Co-ordinated Time
VDL	VHF Digital Link
VDL2	VDL Mode 2
VDL3	VDL Mode 3
VDL4	VDL Mode 4
VOR	VHF Omni-Directional Ranging
WAN	Wide Area Network

A Description of ATM applications

#	ATM application	Description
APP1a	Enhanced surveillance in terminal and en route airspace, limited additional information being displayed to the controller	This ATM application has been selected to map closely with the proposals for an initial package of 3 controller access parameters (CAPs)
APP1b	Enhanced surveillance in terminal and en-route airspace providing a wider range of DAPs	Provision of downlinked data to increase the efficiency for tactically separating aircraft.
APP1c	Enhanced surveillance accuracy for automation tools in terminal and en-route airspace	This ATM application covers the system wide use of DAPs.
APP1d	Fusion of current radar and ADS-B surveillance in terminal and en-route airspace	The purpose of this ATM application is to provide a means for achieving multiple coverage in an environment where radar is mixed with ADS-B surveillance. Provision of surveillance coverage by a similar means in the airport environment is covered by APP13a. This ATM application is not judged to be relevant to remote regions where there is unlikely to be extensive radar coverage.
APP1e	ATC surveillance using ADS-B in terminal and en-route airspace	The purpose of this ATM application is to provide surveillance coverage by ADS-B technology alone. The scope of APP1e is limited to terminal and en-route regions. Provision of surveillance coverage by a similar means in airport and remote regions is covered by APP13b and APP14a respectively.
APP2a	Pilot preferences data link	Downlink of a pilot’s preferred routing.
APP2b	Strategic controller/pilot messages	This includes downstream clearances for oceanic, information on Standard Arrivals (STARS), departure clearances (DCL) at airports.
APP2c	Support for increased automation	This provides a full range of data link services which enable increased automation on the ground.
APP2d	Trajectory negotiation	This provides services supporting 4D trajectory negotiation, conflict free trajectories.
APP3a	Enhanced visual acquisition (EVA) in remote and oceanic airspace	Provides enhanced visual acquisition (EVA) in remote and oceanic airspace
APP3b	Enhanced visual acquisition (EVA) in terminal airspace	Provides enhanced visual acquisition (EVA) in terminal airspace
APP3c	Enhanced visual approaches	Provides enhanced visual approaches
APP3d	Traffic situational awareness in core and transitional en-route airspace	This includes a package of ATM applications: EVA, Enhanced Traffic Information Broadcast (E-TIBA) and Enhanced See and Avoid (E-S&A).
APP4a	Provision of D-OTIS (ATIS, METAR) and D-RVR	This ATM application concerns automation of services that are currently delivered by voice.

#	ATM application	Description
APP4b	Provision of full range of uplink information services	This provides services that are not currently available to the pilot and includes automatic Operation Flight Information Service (OFIS), which will be derived from NOTAM/ Snow Alert (SNOWTAMS) information, SIGMET.
APP7a	Provision of information on route availability (DYNAV)	In addition to an uplink of information on available routes, it is expected that this ATM application will require at least part of the services provided for the PPD ATM application in order to provide efficient coordination with ground systems.
APP9a	Airborne spacing in en-route and terminal airspace	This includes establishing in-trail spacing intervals, level spacing and in-descent spacing in core and transitional en-route and terminal airspace.
APP9b	Crossing and passing in en route airspace	This includes level crossing and passing and vertical crossing in core and transitional airspace.
APP9c	Final approach spacing	This is also known as improved approach spacing (CDTI enhanced flight rules) [115]. Aircraft establish and maintain separations in the approach path. Benefits arise because aircraft have the potential to maintain a separation that is closer to the allowed minimum [38].
APP9d	Departure spacing	Currently departure spacing is generally controlled on a time basis: the time between departures depending on the whether the aircraft will follow or diverge from the preceding aircraft. The result of current operational practice is that aircraft tend to enter terminal airspace at separations that greatly exceed the allowed minimum. Departure spacing using ADS-B has the potential to involve the pilot in collaborative decision making for take off time based on a distance behind the preceding aircraft with the potential to achieve closer separations at the terminal area boundary [38].
APP10a	Airborne separation in oceanic and remote airspace	This includes in-trail climb (ITC), in-trail descent (ITD), lateral passing manoeuvres and station keeping.
APP10b	Airborne separation in en-route and terminal airspace	This includes following, crossing and climb/descent manoeuvres, sequencing applications.
APP10c	Final approach separation	This includes pair approaches and is the progression of APP9c but makes possible reduced approach spacings.
APP11a	Cluster control in ATC managed airspace	This will apply in core and transition airspace.
APP11b	Autonomous operations in FFAS	This is expected to apply initially in remote or transitional en-route airspace and then later to core airspace.
APP12a	Surface enhanced visual acquisition	This is also known as airport surface situational awareness (Visual Flying Rules (VFR) -day and VFR-night) and is expected to provide smoother taxiing in good weather via providing better awareness to the pilots, eliminating some of the constraints imposed by the limited visibility from the cockpit.
APP12b	Runway and final approach occupancy awareness	Provides enhanced awareness of other aircraft and vehicles on the airport surface reducing the risk of runway incursions.

#	ATM application	Description
APP12c	Enhanced IMC airport surface operations	This is similar to surface enhanced visual acquisition (APP12a) but enhances operations in reduced visibility supporting, in particular, landing and take-off and possibly taxi operations.
APP13a	Fusion of current terminal and/or surface radar with other surveillance means	This provides enhanced surveillance accuracy for Center – TRACON Automation System (CTAS) and other terminal automation tools.
APP13b	ATC surveillance using ADS-B at airports.	This enables application of pseudo radar separation standards at airports without radar coverage
APP13c	Routing	This provides routing information such as taxi clearances to aircraft on the airport surface.
APP14a	Basic surveillance infrastructure via ADS-B in remote regions	ADS-B offers the opportunity to provide a basic surveillance picture to ground controllers without the need to provide radar infrastructure.
APP14b	ATS in oceanic/remote areas	This includes controller/pilot data link communications (CPDLC) services and surveillance via ADS-contract (ADS-C). ADS-C offers the opportunity to obtain greater situational awareness in oceanic airspace. ADS-C is able to provide regular position reports, position reports on demand from the controllers and position reports following an event (for example, an aircraft crossing a waypoint). CPDLC provides, for example, clearance delivery. The combination of CPDLC and ADS-C is expected to enable more efficient climb/descent and passing manoeuvres and more efficient lateral passing manoeuvres. In the analysis carried out in this document, it is assumed that the initial implementation of this ATM application will be supported by the FANS1/A equipage.

B Point-to-point architectures requirements

B.1 Objective

B.1.1 The present annex presents the approach adopted for the determination of the technical requirements of the point-to-point communication architecture surrounding the mobile datalink segment in the end-to-end communication chain.

B.1.2 We will see the impact of this inter-networking system on each of the QoS parameter identified in the study.

B.2 ATN architecture

B.2.1 The proposed 'reference' architecture is provided in the following figure.

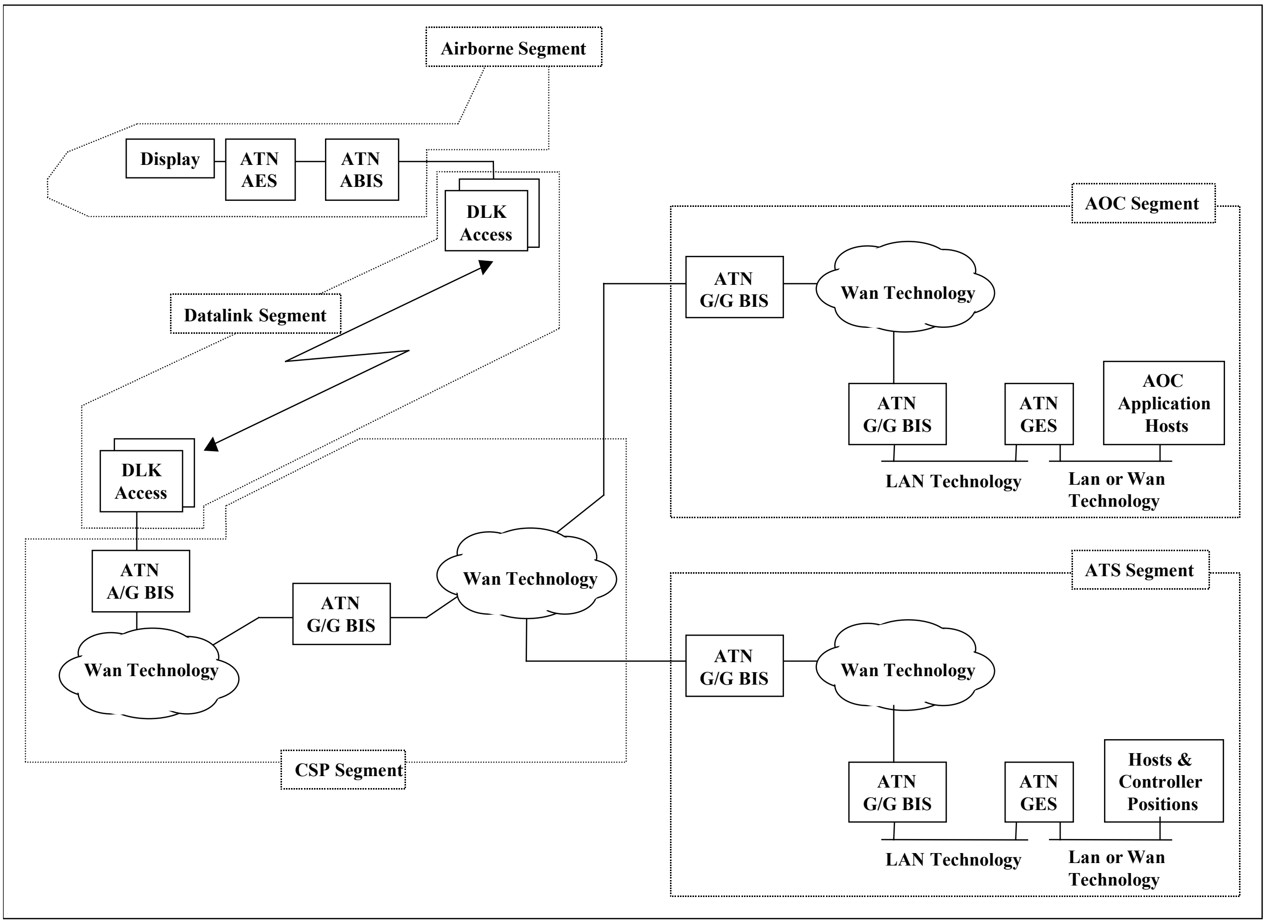


Figure B-1: Proposed reference ATN architecture

B.2.2 The proposed architecture focuses on the network equipment used during end-to-end communication between an airborne application / pilot and a ground end user. In particular, the architecture definition mainly focuses on the type and number of network components involved in the end-to-end communication.

B.2.3 Four different segments have been identified in the proposed reference architecture:

- The Airborne Segment,
- The Communication Service Provider (CSP) segment,
- The Air Traffic Service (ATS) segment,
- The Aeronautical Operational Control (AOC) segment.

These four segments represent the end-to-end communication architecture within which the Datalink segment operates.

B.2.2 Segment definition

B.2.2.1 Airborne segment

B.2.2.1.1 The Airborne segment includes the airborne end-user application, the ATN End System (ES) which may hosts the airborne end-user application and the router (BIS) which provides, through the Datalink segment, a communication path to the ATN Air-Ground Router (A/G BIS) constituting the access to the ground network. The equipment to interface with the network have been included in the Datalink segment.

B.2.2.1.2 In some cases, and depending on the airborne architecture, the ATN ES and router may be merged onto one single system called ES/BIS. For the purpose of the present study, the most stringent case in terms of performance has been selected and therefore each system has been considered as independent.

B.2.2.2 Datalink segment

B.2.2.2.1 The Datalink segment includes the airborne and ground equipment to interface with the network, called generically datalink access equipment (for example Data 3 for AMSS, VDR for VDL2).

B.2.2.2.2 This segment has been created for the purpose of the present study only. In reality, the Datalink access equipment are part of the Airborne segment for the on-board equipment and part of the CSP segment for the ground equipment.

B.2.2.3 Communication Service Provider (CSP) segment

B.2.2.3.1 The CSP segment includes the ATN Air-Ground Router (A/G BIS) and an ATN Ground/Ground BIS. The A/G BIS provides a communication path to the airborne router through the Datalink segment. The G/G BIS provides the ATN service level on the groundside proposed by the service provider[19].

[19] CSP could provide a datalink service only. It should also be noted that this architecture does not prevent ATS providers to act as CSPs.

B.2.2.3.2 It is likely that the communication service providers will deploy a worldwide network based on multiple G/G BIS interconnected through WAN sub network to allow ground customer accesses to any dedicated A/G BIS.

B.2.2.3.3 The ground access to the CSP network is performed through a WAN sub network (typically X.25 or Frame Relay).

B.2.2.4 ATS segment

B.2.2.4.1 The ATS segment includes the ATN Ground End System (GES) and the ATC systems used by the air traffic controller (in some proposed architectures several ground ATS users may share the same ES to communicate with the aircraft). In addition, at the network level, ground routers are deployed according to the routing topology selected by the state/organization in order to support the traffic generated by the ATC Centres.

B.2.2.4.2 For the purpose of the present study, two Ground/Ground routers have been considered. The one defined at the segment boundary is used to illustrate the potential use of a Backbone routing domain in a state/organization deployment.

B.2.2.5 AOC segment

B.2.2.5.1 The AOC Segment includes the ATN Ground End System (GES) and the AOC systems providing the airline staff with the AOC information. As for ATS segment, two ground routers have been considered.

B.2.3 Topology justification

B.2.3.1 Number of ground ATN routers

B.2.3.1.1 The number of ground routers used in the context of an end-to-end communication will mainly depend on the routing organisation and the size of the ATN network: e.g. the deployment of an ATN Backbone although it allows an optimisation of the routing, will increase in general the number of crossed ATN nodes. In addition, the internal network architecture of the involved organisations (CAA, Service Provider) will also impact the number of ATN routers.

B.2.3.1.2 For the purpose of the present study, three ground routers have been considered in the proposed architecture, as this number is likely to be reached in Europe in a short-term period (2010). In a long-term period, although the number is very likely to be higher, it appeared difficult to retain a target architecture on this basis; in addition due to the technology evolution it is difficult to extrapolate the performance of the systems at that time.

B.2.3.2 WAN technology

B.2.3.2.1 The WAN sub-networks could be based on various technologies like X.25, Frame Relay, IP, or ATM. To date, the technology widely in use is X.25, at least for the service interface because of the high quality of service, the flexibility of use, the wide availability and the level of standardisation.

B.2.3.2.2 The first version of the ATN network will use this kind of sub network. In the medium term[20], IP service-based sub networks are likely to be deployed.

B.2.3.2.3 Frame Relay and ATM are technologies that should not be deployed in the short term as no service interface are directly available to users, but might be implemented in the core part of these networks to enhance the performance of the network.[21]

B.2.3.3 LAN technology

B.2.3.3.1 Because of their current and future widespread use, LANs are likely to be present in many parts of the ATN, extending the ATN into sites containing distributed communications systems. For this, ATN routers using the sub network services of WANs and LANs will be necessary as proposed in the 'reference' implementation.

B.2.3.3.2 However LANs will, to a certain extent, be topologically on the "periphery" of the ATN and are therefore not of central importance. They are also highly integrated with and dependent on rapidly changing computer systems implementation.

B.2.3.3.3 Many different LAN technologies are available, with some predominance of Ethernet/FDDI. Assuming a reasonable load on the links, the speed-rates (up to one hundred Mbps) of these local (extent of the network is up to a few hundred meters) links allows to neglect the transit time over the LANs sub network type.

B.3 ATN end-to-end performances

B.3.1 The first part of the Datalink roadmap study has identified the Datalink applications and services that should be supported by the datalink technologies. Quality of service indicators have been defined for applications. They are:

- Time or transit delay
- priority
- integrity
- availability
- message size
- message frequency
- throughput

[20] Standardization of IP subnetwork access is being standardized by ICAO but availability of the associated operational software is very unlikely in the short term period

[21] In its ground ATN network implementation, FAA plans the evolution of the NADIN X.25 packet switching network into an integrated data/voice communication Network (FTI for FAA Telecommunication Network), based on ATM technology and providing IP, X.25, voice service interfaces. This evolution is planned to be phased with intermediate steps.

B.3.2 Time characteristic

B.3.2.1 General remarks

B.3.2.1.1 The Transit delay indicator corresponds to the end-to-end transit delay for a one-way transaction in 95% of the cases. This indicator appears to be a representative indicator to measure the performance of a system regarding the application requirement as relying both on the throughput and the integrity parameters. It has been considered for one end-to-end communication.

B.3.2.1.2 The volume of traffic resulting of the number of aircraft and communications between the aircraft and the ground systems, has not been considered: it has been assumed that the overall network would have to be sized appropriately with a reasonable load. Anyway, the ATN has the benefit of congestion control as well as traffic priority control which, if tuned appropriately with adequately dimensioned ATN components, can avoid a situation where the sub network cannot handle the traffic in good condition due to traffic overload.

B.3.2.2 Segment impact

B.3.2.2.1 The maximum transit delay must be achieved on a global basis, end-to-end across the whole ATN. This implies that each segment of the whole ATN must be allocated a certain value. For each application, the allocation per segment will be discussed.

B.3.2.2.2 The following assumptions have been taken for the transit delay of each ATN entity:

Entity	**Estimate of the Transit Delays of one packet**
WAN	100 ms
G/G BIS	75 ms
A/G BIS	75 ms
LAN	Negligible
ATS Systems	400 ms
AOC Systems	400 ms
Airborne ES & applications	500 ms
Airborne BIS	150 ms
Airborne Display	Negligible

B.3.2.2.3 A datalink application consists of various end-to-end exchanges of PDUs (Protocol Data Units), that are basic packets of small size transmitted by the higher layers of the communication stack. For a typical datalink application described in this study, we can consider that around 4 PDUs have to be exchanged in each direction (uplink and downlink, considering the application as symmetrical).

B.3.3 Transit delay per segment

B.3.3.1 The following table presents the hypotheses adopted and the time delays obtained for each segment of the communication chain:

Segment	Composition	Calculation	Transit Delay
Airborne Segment	1 Airborne ES & applications 1 Airborne BIS 1 Airborne Display	(0.5+0.15)x4	2.5 sec
CSP Segment	1 A/G BIS 2 WANs 1 G/G BIS	(0.075+2x0.1+0.075)x4	1.5 sec
ATS Segment	2 G/G BIS 1 WAN 1 LAN 1 ATS System	(2x0.075+0.1+0.4)x4	2.5 sec
AOC Segment	2 G/G BIS 1 WAN 1 LAN 1 AOC System	(2x0.075+0.1+0.4)x4	2.5 sec

B.3.3.2 The maximum transit delay allowed for the datalink segment is the maximum transit delay allowed by the use of the considered set of applications less the transit delays in all the other segments of the interconnection network.

B.3.3.3 The technology to be chosen for a given set of applications must be compatible with the previous maximum transit delay.

B.3.4 Priority characteristic

B.3.4.1 The ATN, as specified in the SARPs, has a powerful traffic prioritisation mechanism which includes the ability to inhibit certain traffic from using particular routes and can also be used to selectively dump low priority application data traffic in cases where overload traffic condition are reached.

B.3.4.2 Therefore priority will be ensured at each ATN node and priority handling will only be ensured from an end-to-end perspective if the mobile datalink sub network does support prioritisation.

B.3.4.3 The priority being important to distinguish between safety critical and non-safety critical information, non-support of priority handling at the datalink sub network level might be of importance and shall be considered as a potential issue during the ATN deployment.

B.3.5 Integrity characteristic

B.3.5.1 ATN SARPs mandate that the probability of a miss-delivered message must remain undetected in less than 1 in 10^8 cases. Therefore, the end system shall make provisions to ensure that the probability of not detecting a 255-octet message being miss-delivered, non-delivered or corrupted by the Internet communications service is less than or equal to 10^{-8} per message.

B.3.5.2 If data integrity is not ensured at a sufficient level by the mobile datalink sub network, data retransmission will occur based on the Transport protocol mechanism which will likely decrease the performance of the overall system (may impact the time criticality parameter of the application).

B.3.6 Availability characteristic

B.3.6.1 This parameter depends on the reliability of each component of the ATN and the provisions made in its design for alternative routes and provision of redundant systems. Availability can be dealt with only once an initial design and sizing of the ATN has been made. Availability is subject to the topology and configuration of the ATN topology, and certain design principles should be used in proposed ATN topologies to ensure the required availability targets are achievable. These principles should include:

- Duplication of routers, switches and communications links;
- Dual connection of end systems;
- Selection of equipment and communications circuits with appropriate guarantees of MTBF (Mean Time Between Failure) and MTTR (Mean Time To Restore).

B.3.6.2 ATN routing mechanism ensures that alternative route (if any) can be used if a particular link is broken. Anyway, end-to-end availability is directly linked with the end system implementation and in particular how the fail over condition will be handled. As this aspect is not standardised and relies upon each state/organisation choice, it is difficult to extrapolate on this subject.

B.3.6.3 The total end-to-end availability of the communication chain is the mathematical product of the availabilities of all the segments of this chain.

B.3.7 Message size characteristic

B.3.7.1 Any message size limitation imposed by a mobile datalink sub network is bypassed by the use of the ATN segmentation. This segmentation will anyway impact the overall performance of the system and therefore the configuration of each ATN node shall be done carefully to avoid multiplication of PDU on the network due to the segmentation configuration parameters.

B.3.8 Message frequency characteristic

B.3.8.1 This parameter has a direct link to the capacity of the mobile datalink sub network, which in term of capacity is the most restrictive segment in the overall ATN architecture. As explained previously, the sub network and router can operate in a reasonably predictable and stable manner only when traffic loads are kept reasonably low with respect to their theoretical throughputs. However, the requirements and applications do not indicate strong requirements for this parameter.

B.3.8.2 In the short term period, and in regards to the type of application to be deployed, the requested message frequency will be in a range from low (on event more than a minute) to high (every 10 seconds) which are reasonable value compared to mobile sub network capacity. This has to be further analysed based on the network capacity (in regards to the message size) and deployment choice made by each state/organisation

C Cost Assessment

C.1 Introduction

C.1.1 The cost assessment is divided into **technology specific** costs:

- Airborne (avionics) costs;
- Ground station costs;
- Satellite system costs;

and costs which are considered to be **application specific**:

- Ground network and network management costs
- Ground control centre modification costs.

C.1.2 This annex has the following structure:

- **Section C.2**: description of the technology specific cost assumptions;
- **Section C.3**: description of the application specific cost assumptions;
- **Section C.4**: derivation of the technology specific costs;
- **Section C.5**: derivation of the application specific costs;
- **Section C.6**: presents a **cost summary**;
- **Section C.7**: evaluates costs for the scenarios in Section 7.

C.2 Technology specific cost assumptions

C.2.1 General cost assumptions

C.2.1 The general cost assumptions are:

a. Costs can be divided into:
   - initial (non-recurring) costs;
   - maintenance (recurring) costs.

b. Maintenance costs are derived as a percentage of the initial hardware costs.

c. At the time of writing 1 US dollar is within 1% of 1 Euro. In these cost estimations US dollars and Euros have been assumed to be of equal value.

d. Elementary Surveillance is assumed to be in place as a baseline, since this form of surveillance is mandated from 2003.

The remainder of this section describes the derivation of the initial costs.

C.2.2 Assumptions for airborne costs

C.2.2.1 The airborne cost assumptions are:

1. Costs can be divided into:
   - Hardware, including transceiver and antennae;
   - Integration, installation, and certification of the hardware;
   - Operations and maintenance training;
   - Project management.
2. Cost figures for aircraft are based on the cost of a single transceiver installation. Where mitigation is required in the event of equipment failure for safety-critical applications, it is assumed for cost purposes that this will be provided by use of different *systems*.
3. Costs are given assuming retrofit to digital Air Transport aircraft.
4. In general, the Service Bulletin route for upgrade has been assumed. Costs for Service Bulletins for all the different technologies and different retrofit combinations are difficult to obtain, so in most cases the cost of the Service Bulletin is estimated to be 10% of the hardware cost.

C.2.3 Assumptions for ground transponder costs

C.2.3.1 The ground cost assumptions are:

1. It is assumed that there is an existing ground station site (i.e. no purchase of land, connection to power supply, back-up power supplies to be costed).
2. Ground station costs can be divided into:
   - Hardware cost, including transceiver and antennae;
   - Installation and certification, of the hardware;
3. Cost figures for ground stations are based on the cost of a single transceiver installation. Where mitigation is required in the event of equipment failure for safety-critical applications, it is assumed for cost purposes that this will be provided by use of different *systems*.
4. Satellite system costs (where applicable) are divided into:
   - Satellite ground station costs (evaluated as in assumption 1 above)
   - Satellite build cost;
   - Satellite launch cost;

5. The number of VHF and 1090 ES ground stations required in Europe is estimated based on 1 ground station per major airport (> 1 million passengers per year) plus 1 ground station per ACC. There are about 89 airports in Europe with more than 1 million passengers a year (1998 figures) [241], and 61 ACCs [158]. Thus we assume 150 ground stations are required. This method of calculation has been used previously [239]. The number of 150 compares with a lower figure of 130 ground stations (not justified) in [239] for 33 states, and a figure of 170 ground stations suggested by [229].

C.3 Application specific cost assumptions

C.3.1 Assumptions for ground network costs

C.3.1.1 Network costs are divided into:

- ATN network costs;
- Aircraft Derived Data (ADD) network costs;
- TIS-B network costs.

C.3.1.2 The network costs for Enhanced Surveillance are included in the ADD network costs, for which the cost of the required networks has been taken from a previous study [230].

C.3.1.3 For the TIS-B re-broadcast functionality, for which a high ground-ground data rate is required, the network costs have been estimated very approximately by basing them on the figures available for Enhanced Surveillance.

C.3.2 Assumptions for centre costs

C.3.2.1 The calculations for centre costs involve assuming a number of controller working positions (CWPs) in Europe, and estimating the cost to upgrade each CWP.

C.4 Technology specific cost derivations

C.4.1 HFDL ground costs

C.4.1.1 A world-wide ground network already exists for the HF voice service, provided by ARINC. The cost involved in implementing an HFDL ground network is assumed to be the cost of installing HF data link transceivers at existing ARINC HF or VHF ground stations. The cost of such an upgrade is documented in ICAO ALLPIRG cost tables at $48,000 [163].

C.4.1.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.1.3 The total cost of upgrading one ground station to HF data link is then **€57,600** (single installation).

C.4.1.4 ARINC has so far installed 13 HF data link ground stations. The exact number of ground stations that will be required worldwide in the future to provide further capacity and coverage is unknown. The future requirements will depend on the take-up of the service by aircraft. However we estimate that a total of 20 stations are needed worldwide for complete coverage.

C.4.1.5 The cost to provide all 20 ground stations is then **€1,152,000** (single installation). It should be noted that this represents an investment cost that has already been spent (or budgeted for), and is a cost not borne solely by users of European ATM.

C.4.1.6 Network and centre costs are assumed to be negligible, as the service provider is expected to use its existing networks built for HF voice and VHF.

C.4.2 HFDL airborne costs

C.4.2.1 Airborne costs are based on the price of a commercially available Honeywell HF Data Link transceiver (Honeywell XK516D1), with a list price of €59,100 [217].

C.4.2.2 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.2.3 This results in an estimated cost per aircraft to upgrade to HFDL of **€70,920** (single installation).

C.4.3 AMSS ground costs

C.4.3.1 Inmarsat already provides an AMSS service. The cost of a complete AMSS ground station is documented in ICAO ALLPIRG cost tables at €15,000,000 [163].

C.4.3.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.3.3 The total cost of an AMSS ground station is then estimated as **€18,000,000**. The number of AMSS ground stations required in the ground network in Europe is estimated to be 3 [261]. This gives the total ground system cost for AMSS to be approximately **€54,000,000**.

C.4.3.4 Network and centre costs are assumed to be included in the above costs.

C.4.4 AMSS satellite costs

C.4.4.1 Inmarsat-4 will utilise two satellites with one spare. The hardware cost per satellite is estimated at €140,000,000 [235]. The launch cost per satellite is estimated as €70,000 [235]. Project management is estimated at 100,000 man-hours, or €10,000,000. This gives a total cost per satellite of €220,000,000. For three satellites, the cost is **€660,000,000**.

C.4.5 AMSS total fixed system cost

C.4.5.1 The total cost of the provision of the AMSS network in Europe is thus estimated as **€714,000,000**. This compares with a reported world-wide cost of the Inmarsat-4 system of $1.4 billion from reference [236]. This represents an investment cost that has already been spent, and is a cost not borne solely by users of European ATM.

C.4.6 AMSS airborne costs

C.4.6.1 The purchase price of an AMSS on-board transceiver varies according to the functionality required, including the number of channels needed. For a medium range transceiver with 4 channels (SAT-2000-3), Rockwell Collins give a list price of $179,392 [218]. This includes the antenna.

C.4.6.2 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.6.3 This results in an estimated cost per aircraft to upgrade to AMSS of **€215,270** (single installation).

C.4.7 VDL2 ground costs

C.4.7.1 The cost of a VDL2 ground station, including installation, has been quoted as being around €75,000 [232].

C.4.7.2 Around 150 VHF ground stations are assumed to be needed to provide sufficient coverage in Europe (see general assumptions above). This leads to a total cost for all European VDL2 ground stations of **€10,800,000** (single transceiver).

C.4.7.3 Network and centre costs are assumed to be negligible, as the service provider is expected to use its existing networks built for HF voice and VHF.

C.4.8 VDL2 airborne costs

C.4.8.1 Airborne costs for a VDL2 transceiver are based on the current VHF transceiver costs in the Rockwell Collins price list, of €49,400 [218]. It is assumed that an installation will use existing VHF antennas on board the aircraft.

C.4.8.2 It is assumed that a Communications Management Unit (CMU) will be required, since VDL2 is expected to be the first data communication system fitted after ACARS. ACARS systems do not use a CMU, whereas one will be required for VDL2 (and other systems such as VDL3 and VDL4). The cost of a CMU is taken from the Rockwell Collins price list to be €47,000 [218].

C.4.8.3 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.8.4 This results in an estimated cost per aircraft to upgrade to VDL2 of **€115,680** (single transceiver).

C.4.9 1090 ES ground costs

C.4.9.1 1090 Extended Squitter ground stations are expected to be provided by new omni-directional antennas, connected to transponders capable of receive only or receive and transmit. The cost of such a system including the antenna is estimated to be €75,000 [231].

C.4.9.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.9.3 The total cost of a 1090 ES ground station is then estimated as **€90,000** (single transceiver).

C.4.9.4 It has been assumed that approximately 150 ground stations would be required in Europe (see general assumptions above), leading to an estimate of the cost to provide all the 1090 ES ground stations in Europe of **€13,500,000** (single transceiver).

C.4.9.5 Network and centre costs are assumed to be negligible, as the service provider is expected to use its existing networks built for HF voice and VHF.

C.4.10 1090 ES airborne costs

C.4.10.1 The cost of a 1090 ES transceiver is estimated from the Rockwell Collins price for their TPR901 Mode S transponder to be €40,600 [218]. It is assumed that a Radio Control Panel (RCP) must be fitted at the same time, costing €16,400 [218].

C.4.10.2 For a percentage of the aircraft, a transceiver and RCP capable of 1090 ES may have already been provided by the upgrade to Mode S Enhanced Surveillance or even to meet the Elementary Surveillance mandate in 2005. The airborne costs for 1090 ES have therefore been calculated twice, once with the transceiver and RCP already provided, and once without. The remaining installation work (with costs below) is assumed necessary for all aircraft.

C.4.10.3 It is assumed that a GPS antenna is required at a cost of €1,500.

C.4.10.4 For 1090 ES, the baseline is no previous ADS-B system on board the aircraft. Thus a CDTI, or a software modification to the Primary Flight Display, will have to be installed. This cost has been estimated in [38] to be €68,000 for a dual CDTI installation.

C.4.10.5 It is assumed that an upgrade to the FMS will be required, as parameters within the FMS will need to be sent to the 1090 ES unit. The cost of an FMS upgrade has been given in [38] to be €68,000.

C.4.10.6 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.10.7 Due to the introduction of ADS-B on-board, and the modifications to the pilots' display area, it will be necessary to retrain the aircraft crew. Theoretical training of 6 crew has been costed at €4,000 in [38]. Simulator training of 6 crew has been costed at €77,000 in [38]. Upgrade of the simulator has been costed at €8,000 [38].

C.4.10.8 This results in an estimated cost per aircraft to upgrade to 1090 ES of **€322,400** (single transceiver) where transceiver and RCP are required, and **€231,400**, where transceiver and RCP are not required.

C.4.11 Mode S Enhanced Surveillance ground costs

C.4.11.1 It has been assumed that Elementary Surveillance is in place as a baseline for the purposes of calculating costs. The costs required are those involved in the transition from Elementary to Enhanced Surveillance.

C.4.11.2 The Eurocontrol study, the Case for Enhanced Surveillance in Europe (ESDAP) [237], showed that no upgrade of ground Mode S sensors was required in moving from Elementary to Enhanced Surveillance. This was also accepted in the Revised Case for Enhanced Surveillance [23]. However there were ground network and centre costs associated with this transition.

C.4.11.3 The ESDAP study was carried out for the Core Region of Europe, and assumed 88 Mode S sensors required upgrade. For the whole of Europe it is estimated that of order 150 sensors would be involved in the upgrade. Thus in order to obtain figures for the whole of Europe, the network and centre costs involved in the upgrade to Enhanced surveillance have been multiplied by a factor of 1.48 (=150/88).

C.4.11.4 This results in network costs of €11,900,000, and centre costs of €76,700,000. The total ground cost for Enhanced Surveillance for Europe is then estimated as **€88,600,000**. This cost is included in the network and centre costs derived in Section C.5, but excluded from the summary of ground costs in Section C.6, since those costs exclude networks and centres.

C.4.12 Mode S Enhanced Surveillance airborne costs

C.4.12.1 The cost of a Mode S transceiver is obtained from the current Rockwell Collins list price for a Mode S transceiver at €40,600 [218]. A radio control panel (RCP) is also assumed to be necessary at €16,400 [218].

C.4.12.2 Mode S transceivers are currently advertised as being capable of Elementary and Enhanced Surveillance and of 1090 ES. It is assumed here that many airlines will equip with a transceiver capable of Enhanced Surveillance (and possibly 1090 ES), while upgrading to Elementary Surveillance to meet the Europe-wide mandate of Elementary Surveillance in 2003.

C.4.12.3 We estimate that a percentage of AT aircraft will by 2005 have fitted a Mode S transceiver capable of Enhanced Surveillance The airborne costs for Mode S ES have therefore been calculated twice, once with the transceiver and RCP already provided, and once without. The other costs are assumed to be necessary in all cases to adapt the aircraft to make full use of the capability of the transceiver.

C.4.12.4 For the case where the transceiver and RCP require upgrade, installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.12.5 For the case where the transceiver and RCP are assumed already provided, Airbus provided costs of €2,500 for installation kit and service bulletin combined, and 30 man-hours, or €2,400 for labour.

C.4.12.6 The total cost per aircraft is then calculated to be **€68,400** (single transceiver) where transceiver and RCP are required, and **€4,900**, where transceiver and RCP are not required.

C.4.13 VDL3 ground costs

C.4.13.1 The cost of a VDL3 ground station is estimated from discussion with Park Air Systems [238]. The cost is in the region of €150,000-200,000 if the equipment has to be networked to VHF and UHF analogue circuits, and around €100,000-150,000 if the ground stations are being incorporated into a digital only network.

C.4.13.2 As the initial deployment involves routing to analogue VHF and UHF circuits, whereas future deployment is likely to encounter digital circuits, a middle figure of €150,000 has been taken.

C.4.13.3 Installation and certification is assumed to be 20% of the hardware cost.

C.4.13.4 The estimated cost per VDL3 ground station is then **€180,000** (single transceiver).

C.4.13.5 The number of VDL3 ground stations required in Europe is assumed to be 150 (see general assumptions above). This gives an estimated cost to provide all the VDL3 ground stations in Europe of **€27,000,000** (single transceiver).

C.4.13.6 Network and centre costs are assumed to be negligible, as the service provider is expected to use its existing networks built for HF voice and VHF.

C.4.14 VDL3 airborne costs

C.4.14.1 Airborne costs for a VDL3 transceiver are based on the VHF transceiver costs used in the Eurocontrol ADS CBA, of €56,500 [38]. It is assumed that an installation will use existing VHF antennas on board the aircraft.

C.4.14.2 It is assumed that an upgrade Communications Management Unit (CMU) will be required, since VDL2 is assumed to exist already on board the aircraft, with an upgradeable CMU. The cost of a CMU upgrade is estimated to be €8,000 from a Mitre air transport avionics cost estimation [216]. Also from the Mitre document, an upgrade to the Data Link Control Display Unit (DCDU) is foreseen, costing €6,000 [216].

C.4.14.3 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.14.4 This results in an estimated cost per aircraft to upgrade to VDL3 of **€108,900** (single transceiver).

C.4.15 VDL4 ground costs

C.4.15.1 Ground costs for VDL4 have been evaluated for three distinct cases: ground stations capable of point-to-point and broadcast communications; ground stations capable of point-to-point only; and ground stations capable of broadcast only.

Point-to-point and broadcast

C.4.15.2 The ground transceiver cost for VDL4, with both broadcast and point-to-point functionality, has been obtained from discussion with CNS Systems to be €150,000 [229].

C.4.15.3 Installation and certification is assumed to be 20% of the hardware cost.

C.4.15.4 The estimated cost to provide a VDL4 ground station for both point-to-point and broadcast is then **€180,000** (single transceiver).

C.4.15.5 The number of VDL4 ground stations required in Europe is assumed to be 150 (see general assumptions above). This gives an estimated cost to provide Europe-wide coverage of VDL4 for both point-to-point and broadcast of **€27,000,000** (single transceiver).

Point-to-point

C.4.15.6 For point-to-point coverage only, the cost of the ground transceiver reduces to €110,000 [229]. This gives a total ground station cost, including installation, of **€132,000** (single transceiver).

C.4.15.7 Assuming 150 ground stations, the cost to provide Europe-wide coverage of VDL4 for point-to-point applications would be **€19,800,000** (single transceiver).

C.4.16 Broadcast only

C.4.16.1 For broadcast coverage only, the cost of the ground transceiver is €140,000 [229]. This gives a total ground station cost, including installation, of **€168,000** (single transceiver).

C.4.16.2 Assuming 150 ground stations, the cost to provide Europe-wide coverage of VDL4 for broadcast applications would be **€25,200,000** (single transceiver).

C.4.17 VDL4 airborne costs

C.4.17.1 Airborne costs for VDL4 have been evaluated for three distinct cases: airborne stations capable of point-to-point and broadcast communications; airborne stations capable of point-to-point only; and airborne stations capable of broadcast only.

C.4.17.2 For the case where point-to-point and broadcast are considered together, two separate baseline scenarios have been evaluated. In the first scenario, ACARS and Elementary Surveillance are assumed as the baseline communications and surveillance systems on board the aircraft. In the second scenario, it is assumed that VDL2 has already been installed, and that ADS-B-in has been in operation with 1090 Extended Squitter. In the first scenario it is assumed that a CMU and a CDTI do not exist on board the aircraft, while in the second it is assumed that they do.

C.4.17.3 Where point-to-point and broadcast functionality are considered separately, only the baseline scenario with VDL2/1090ES already installed is assumed.

Point-to-point and broadcast (baseline ACARS/Elementary Surveillance)

C.4.17.4 Airborne costs for VDL4 have been largely taken from the Eurocontrol ADS Stage 1 CBA [38]. The cost of a VDL4 airborne transceiver has been taken to be €45,000 [38]. CNS Systems indicated that the price for production units would be between €30,000 and €45,000 and that prototype units used for NUP were €50,000.

C.4.17.5 It is assumed that 2 new antennas are required on the aircraft, at a cost of €2,000 [38], and that a GPS antenna is required at €1,500.

C.4.17.6 ACARS communication systems do not use a CMU. It is assumed that a Communications Management Unit (CMU) will be required for point-to-point communications with VDL4. The cost of a CMU is taken from the Rockwell Collins price list to be €47,000 [218].

C.4.17.7 In this scenario, the baseline is no previous ADS-B system on board the aircraft. Thus a CDTI, or a software modification to the Primary Flight Display, will have to be installed. This cost has been estimated in [38] to be €68,000 for a dual CDTI installation.

C.4.17.8 It is assumed that an upgrade to the FMS will be required, as parameters within the FMS will need to be sent to the 1090 ES unit. The cost of an FMS upgrade has been given in [38] to be €68,000.

C.4.17.9 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.17.10 Due to the introduction of ADS-B on-board, and the modifications to the pilots' display area, it will be necessary to retrain the aircraft crew. Theoretical training of 6 crew has been costed at €4,000 in [38]. Simulator training of 6 crew has been costed at €77,000 in [38]. Upgrade of the simulator has been costed at €8,000 [38].

C.4.17.11 This results in an estimated cost per aircraft to upgrade to VDL4, from ACARS/Elementary Surveillance, for point-to-point and broadcast of **€380,600** (single transceiver).

Point-to-point and broadcast (baseline VDL2/1090 ES)

C.4.17.12 For the baseline scenario in which VDL2 and 1090 ES are already installed on the aircraft, it is assumed that a CMU and a CDTI are in situ, and the cost is reduced to an upgrade of these two components. The CMU and CDTI upgrade costs are estimated as €8,000 [216] and €10,000, respectively. The FMS upgrade is not required in this case.

C.4.17.13 As the CDTI is not new to the aircraft, the crew training costs (theoretical training, simulator training, and simulator upgrade) associated with its introduction are not required.

C.4.17.14 With these differences, the estimated cost per aircraft to upgrade to VDL4, from VDL2/1090 ES, for point-to-point and broadcast is **€93,600** (single transceiver).

Point-to-point (baseline VDL2/1090 ES)

C.4.17.15 For point-to-point capability only on board the aircraft, a CMU upgrade is required. However, none of the costs associated with ADS-B apply, such as the CDTI, the FMS upgrade, the GPS antenna, or the crew retraining.

C.4.17.16 The estimated cost per aircraft to upgrade to VDL4, from VDL2/1090 ES, for point-to-point functionality only is then **€79,800** (single transceiver).

Broadcast only (baseline VDL2/1090 ES)

C.4.17.17 For broadcast capability only on board the aircraft, a CMU upgrade is not required, but a CDTI upgrade is assumed to be needed. The FMS upgrade is not required in this case.

C.4.17.18 The estimated cost per aircraft to upgrade to VDL4, from VDL2/1090 ES, for broadcast functionality only is then **€84,000** (single transceiver).

C.4.18 UAT ground costs

C.4.18.1 The cost of a UAT ground transceiver has been obtained from discussion with Sensis corporation [231]. From this source, the cost, including the antenna, was given as between $50-100,000 depending on the capability required. We assume an average value of €75,000.

C.4.18.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.18.3 The estimated cost per VDL3 ground station is then **€90,000** (single transceiver).

C.4.18.4 The number of UAT ground stations required in Europe is assumed to be 150 (see general assumptions above). This gives an estimated cost to provide all the UAT ground stations in Europe of **€13,500,000** (single transceiver).

C.4.18.5 Network and centre costs are assumed to be negligible, as the service provider is expected to use its existing networks built for HF voice and VHF.

C.4.19 UAT airborne costs

C.4.19.1 Airborne costs for a UAT transceiver are based on the VHF transceiver costs used in the Eurocontrol ADS CBA, of €56,500 [38]. It is assumed that an installation will require a GPS antenna costing €1,500 [38].

C.4.19.2 It assumed that a CDTI is already in place on board the aircraft, as ADS-B is expected to have already been implemented with 1090 ES. An upgrade to the CDTI will be needed at an estimated cost of €10,000. The FMS upgrade is not required in this case.

C.4.19.3 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.19.4 This results in an estimated cost per aircraft to upgrade to UAT of **€81,600** (single transceiver).

C.4.20 Gatelink ground costs

C.4.20.1 The approximate cost of a wireless LAN system is given by the Eurocontrol Wireless Airport Communication System (WACS) Study [194].

C.4.20.2 In the WACS study the cost is evaluated for one Access Point (antenna system) at an airport. A Gatelink solution at an airport includes:

- Access Points, including antenna, cabling;
- LAN bridges, and connection to the wired LAN with cabling, connectors;
- Power supply;
- Outdoor mounting equipment.

C.4.20.3 Multiple Access points will be required – about 12 being needed for a large airport such as Frankfurt. For Frankfurt, the cost per access point is given as being around $5000. This gives the expected cost of the whole ground system at Frankfurt as $60,000.

C.4.20.4 While other smaller airports may require fewer Access Points, the cost per Access Point would be expected to increase for smaller installations. The study also quotes some different costs per Access Point, ranging from $4000 to $10,000.

C.4.20.5 For this cost analysis we shall assume (assuming the current parity of $ and €) that the cost per airport is around €60,000, excluding installation.

C.4.20.6 Installation and certification is assumed to be high (compared to the hardware cost, due to the need to design the position of access points to suit the layout of individual airports. This is estimated at €20,000.

C.4.20.7 The estimated cost per airport is then likely to be around **€80,000** (single installation).

C.4.20.8 The larger airports are the most likely to implement a Gatelink system, and there are about 90 airports in Europe with more than 1 million passengers per year [241]. This allows us to estimate that the total ground cost to install Gatelink in Europe is of order **€7,200,000** (single installation).

C.4.21 Gatelink airborne costs

C.4.21.1 The hardware cost of a Gatelink system onboard an aircraft is given in the WACS study to be approximately $100,000. This includes:

- server interface unit;
- network server unit;
- terminal wireless LAN unit;
- antenna.

C.4.21.2 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.21.3 This results in an estimated cost per aircraft to install a Gatelink system of **€120,000** (single installation).

C.4.22 NGSS ground costs

C.4.22.1 Ground station cost for NGSS are based on those for AMSS, for which the cost of a ground station was given as €15,000,000 [163].

C.4.22.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.22.3 The total cost of an NGSS ground station is then estimated as **€18,000,000**.

C.4.22.4 The cost of the networks linking the ground stations is assumed to be included in the ground station cost.

C.4.22.5 The Iridium network requires around 30 ground stations [224]. The total ground station cost for the Iridium NGSS network is thus approximately **€540,000,000**.

C.4.23 NGSS satellite costs

C.4.23.1 The total cost of an Iridium satellite is estimated from references [221,223] to be about €25,000,000. The launch cost is estimated from references [222,223] to be about €15,000,000. In addition to these costs we assume 40,000 hours of project management (at 100 euro/hour). This gives a total cost to provide each satellite of **€44,000,000**.

C.4.23.2 The Iridium constellation consists of 66 satellites plus 7 spares. However a total of 88 satellites were launched, with several failures. This equates to a total satellite cost of around **€3.9 billion**.

C.4.24 NGSS total fixed system cost

C.4.24.1 The total cost of the NGSS network is thus estimated as **€4.4 billion**. This compares with a reported cost of the Iridium network of $5 billion from reference [223]. This represents an investment cost that has already been spent, and is a cost not borne solely by users of European ATM.

C.4.25 NGSS airborne costs

C.4.25.1 The cost of an airborne transceiver operating over the Iridium network has been obtained from reference [220] to be €29,500, which is the cost of the Honeywell Airsat 1 system. This is the cost of a unit for business aircraft, which is likely to be an underestimate of the cost for air transport aircraft. It includes the cost of the antenna.

C.4.25.2 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.25.3 This results in an estimated cost per aircraft to install an NGSS system of **€35,400** (single transceiver).

C.4.26 SDLS ground costs

C.4.26.1 Initial implementations of SDLS may use existing AMSS ground stations. A longer term implementation may consist of around 40 small GESs placed near existing ATC centres [200]. The ground costs for SDLS have been estimated assuming about €1,000,000 for the cost of a small GES.

C.4.26.2 Installation and certification is assumed to be 20% of the hardware cost.

C.4.26.3 The total cost of an SDLS ground station is then estimated as **€1,200,000**. With 40 ground stations, this gives the total ground system cost for SDLS to be approximately **€48,000,000**.

C.4.26.4 Network and centre costs are assumed to be included in the above costs.

C.4.27 SDLS satellite costs

C.4.27.1 The build and launch costs for the SDLS geostationary satellites are based on those of the Inmarsat-4 satellites. For these, the hardware cost per satellite was estimated at €140,000,000 [235], and the launch cost per satellite was estimated as €70,000 [235]. Project management is estimated at 100,000 man-hours, or €10,000,000. This gives a total cost per satellite of **€220,000,000**.

C.4.27.2 The cost of 1 in-orbit satellite for SDLS, plus 1 in-orbit spare, is then **€440,000,000**.

C.4.28 SDLS total fixed system cost

C.4.28.1 The total cost of the SDLS network is thus estimated as **€488,000,000**.

C.4.29 SDLS airborne costs

C.4.29.1 Airborne costs for SDLS are assumed to be similar to those for AMSS, for which the cost of an airborne receiver was taken to be €179,392.

C.4.29.2 Installation kits are estimated to be 5% of the initial hardware cost, and service bulletin costs are estimated at 10% of the initial hardware cost. It is estimated that labour is 5% of the hardware cost.

C.4.29.3 This results in an estimated cost per aircraft to upgrade to SDLS of **€215,270** (single installation).

C.5 Application specific cost derivations

C.5.1 Network costs

C.5.1.1 ATN network costs

C.5.1.1.1 The following table shows the costs to provide an ATN network in Europe. The costs are from a review in the Eurocontrol Cost Database (Studies) document of the COPICAT study on ATN deployment in Europe [228].

	ATN related cost (euro)	Number required in Europe	Total cost for Europe (euro)
National router	50,000	186	9,300,000
International router	165,000	61	10,065,000
Applications server (includes ADS, ATIS, CMA, CPDLC, AIDC, AMHS)	475,000	201	95,475,000
Local network management	250,000	141	35,250,000
International network management	6,000,000	1	6,000,000
Subnetworks – VDR	70,000	130	9,100,000
Subnetworks – Mode S	1,000,000	10	10,000,000
Engineering	30% of capital expenditure		52,557,000
Total cost for an ATN network in Europe			**228 M**

C.5.1.2 ADD network costs

C.5.1.2.1 The following table shows the estimated cost to provide an Aircraft Derived Data (ADD) network in Europe. The costs are based on those to provide the networks to support Mode S Enhanced Surveillance as described in the Eurocontrol ESDAP report [237] and the Eurocontrol Revised Case for Enhanced Surveillance [23].

	Cost in euro	Notes
Cost to upgrade networks for Enhanced Surveillance in core Europe	7 M	Figure for 88 Mode S sensors [237, 23]
Additional cost assumed for the rest of Europe	4.9 M	Estimated figure for an additional 62 sensors (total assumed 150)
Estimated cost to provide ADD networks in Europe	**11.9 M**	

C.5.1.3 TIS-B network costs

C.5.1.3.1 The following table estimates TIS-B server/processor and TIS-B network costs for Europe.

C.5.1.3.2 The cost of a TIS-B server/processor is estimated from the cost of a Ground Data Link Processor in the Eurocontrol CBA of D-OTIS and DSC data link services [228]. The number of these required in Europe is estimated assuming one per ACC, of which there are 61 in Europe, plus one per major airport – there are 89 airports with more than one million passengers per year [241].

	Cost in euro	Notes
TIS-B server/processor	200,000	Estimate from [228]
No of TIS-B server/processor required in Europe	150	Estimate based on one per ACC (61 in Europe [158]) and one per airport with more than 1 M passengers per year (89 in Europe [241])
Estimated cost to provide TIS-B server/processors in Europe	**30 M**	
Estimated cost to provide TIS-B networks in Europe	**11.9 M**	Figure based on Mode S ES network cost for 150 centres
Estimated cost to provide TIS-B server/processors and networks in Europe	**41.9 M**	

C.5.2 ATC control centre upgrade costs

C.5.2.1 The following table estimates ATC centre upgrade costs in Europe due to the introduction of datalink services.

C.5.2.2 The number of controller working positions in Europe has been estimated from the number of ATCOs in Europe, obtained as 16,884 from Eurocontrol PRR5 [158], divided by 5 ATCOs per CWP. We assume the ATCOs have four shifts per day, with some ATCOs in management or on leave.

C.5.2.3 We then estimate a cost of € 200 to upgrade each CWP, based on figures in the Eurocontrol ARTAS CBA. We assume this includes the cost of controller retraining.

	Value	Notes
Number of controller working positions (CWPs) in Europe	3400	Based on 16884 ATCOs in 2000, from PRR5 [158], with 5 ATCOs per CWP
Cost to upgrade each CWP	200,000 euro	Estimated figure from ARTAS CBA [244]
Estimated cost to upgrade controller working positions in Europe	**680 Meuro**	

C.6 Cost summary

C.6.1 Summary of ground costs for the broadcast technologies

C.6.1.1 The following table summarises the ground costs for the broadcast technologies. The costs include the ground station (transceiver + antenna), but exclude the network and ATC centre upgrade costs.

C.6.1.2 The non-recurring costs for Mode S Enhanced Surveillance are shown as zero, since no sensor upgrade costs were identified in the Eurocontrol ESDAP study [237], or the Revised Case for Mode S Enhanced Surveillance [23]. In those studies, significant network and ATC centre upgrade costs were identified for the upgrade to Mode S Enhanced Surveillance. These costs have been assumed here to apply generally to provision of ADD, over all technologies, and are included in the application specific costs detailed in Section C.5.

C.6.1.3 A detailed description of the approach used in deriving these costs is given in Section C.4.

Costs in euro	Mode S Enhanced Surveillance	1090 ES	UAT	VDL4 Broadcast
Baseline assumed	Mode S Elementary Surveillance	Existing ground station site	Existing ground station site	Existing ground station site
Cost of ground station	0	75,000	75,000	140,000
Installation	0	15,000	15,000	28,000
Total initial cost per ground station (1 transceiver)	**0**	**90,000**	**90,000**	**168,000**
Yearly maintenance costs per ground station (1 transceiver)	0	7,500	7,500	14,000
Number of ground stations required in Europe	150	150	150	150
Total ground station costs (1 transceiver)	**0**	**13.5 million**	**13.5 million**	**25.2 million**

C.6.2 Summary of airborne costs for the broadcast technologies

C.6.2.1 The following table summarises the airborne costs for the broadcast technologies. A detailed description of the approach used in deriving these costs is given in Section C.4.

Costs in euro	Mode S Enhanced Surveillance	Mode S Enhanced Surveillance	1090 ES	1090 ES
Baseline assumed	Mode S Elementary Surveillance. Transceiver & RCP not previously installed	Mode S Elementary Surveillance. Transceiver & RCP already installed.	Transceiver, RCP & CDTI not previously implemented	Transceiver & RCP already installed. CDTI not previously installed
Hardware				
Cost of transceiver	40,600 [Note 1]	n/a [Note 2]	40,600 [Note 3]	n/a [Note 4]
Radio control panel (x 2)	16,400 [Note 1]	n/a [Note 2]	16,400 [Note 3]	n/a [Note 4]
Antenna (x 2)	n/a	n/a	n/a	n/a
GPS antenna	n/a	n/a	1,500	1,500
CDTI (x 2)	n/a	n/a	68,000	68,000
Upgrade of CDTI	n/a	n/a	n/a	n/a
Upgrade of FMS	n/a	n/a	68,000	68,000
Integration, installation & certification				
Installation kit(s)	2,850	2,500 [Note 2]	9,725	2,500 [Note 4]
Service bulletin	5,700	n/a [Note 2]	19,450	n/a [Note 4]
Man-hours (80 euro/hour)	2,850	2,400 [Note 2]	9,725	2,400 [Note 4]
Operations & maintenance training				
Crew (6 crew) simulator training	n/a	n/a	77,000	77,000
Crew (6 crew) theoretical training	n/a	n/a	4,000	4,000
Simulator modification	n/a	n/a	8,000	8,000
Total initial costs per aircraft (1 transceiver)	**68,400**	**4,900**	**322,400**	**231,400**
Yearly maintenance costs per aircraft (1 transceiver)	5,700	n/a	19,450	13,750

Note 1: These figures assume a new transceiver and RCP are required. This will apply for a certain percentage of aircraft.

Note 2: These figures (from Airbus) assume a transceiver and RCP have already been installed in the upgrade to Elementary Surveillance. This will apply for a certain percentage of aircraft.

Note 3: These figures assume a new transceiver and RCP are required. This will apply for a certain percentage of aircraft.

Note 4: These figures (from Airbus) assume a transceiver and RCP have already been installed in the upgrade to Elementary or Enhanced Surveillance. This will apply for a certain percentage of aircraft.

Costs in euro	**UAT**	**VDL4 Broadcast**
Baseline assumed	CDTI previously installed	CDTI previously installed
Hardware		
Cost of transceiver	56,500	45,000
Radio control panel (x 2)	n/a	n/a
Antenna (x 2)	n/a	2,000
GPS antenna	1,500	1,500
CDTI (x 2)	n/a	n/a
Upgrade of CDTI	10,000	10,000
Upgrade of FMS	n/a	n/a
Integration, installation & certification		
Installation kit(s)	3,400	3,500
Service bulletin	6,800	7,000
Man-hours (80 euro/hour)	3,400	3,500
Operations & maintenance training		
Crew (6 crew) simulator training	n/a	n/a
Crew (6 crew) theoretical training	n/a	n/a
Simulator modification	n/a	n/a
Total initial costs per aircraft (1 transceiver)	**81,600**	**84,000**
Yearly maintenance costs per aircraft (1 transceiver)	6,800	7,000

C.6.3 Summary of ground costs for the point-to-point technologies

C.6.3.1 The following table summarises the ground system costs for the point-to-point technologies with no satellite component. The costs include the ground station (transceiver + antenna), but exclude the network and ATC centre upgrade costs.

C.6.3.2 A detailed description of the approach used in deriving these costs is given in Section C.4.

Costs in euro	**HFDL**	**VDL2**	**VDL3**	**VDL4** **Point-to-point**
Baseline assumed	Existing HF voice ground station	Existing ground station site	Existing ground station site	Mode S Elementary Surveillance
Cost of ground station	48,000	60,000	150,000	110,000
Installation	9,600	12,000	30,000	22,000
Total initial cost per ground station (1 transceiver)	**57,600**	**72,000**	**180,000**	**132,000**
Yearly maintenance costs per ground station (1 transceiver)	4,800	6,000	15,000	11,000
Number of ground stations required in Europe	20	150	150	150
Total ground station costs (1 transceiver)	**1.2 million**	**10.8 million**	**27.0 million**	**19.8 million**

C.6.3.3 The following table summarises the non-aircraft system costs for the point-to-point technologies with a satellite component. The ground costs include the ground earth stations (GESs), the cost of the satellites, and the satellite launch costs, but exclude the network and ATC centre upgrade costs.

C.6.3.4 A detailed description of the approach used in deriving these costs is given in Section C.4.

Costs in euro	**AMSS**	**NGSS**	**SDLS**
Baseline assumption	n/a	n/a	Existing ground station site
Cost of ground station	15,000,000	15,000,000	1,000,000
Installation	3,000,000	3,000,000	200,000
Total initial cost per ground station	**18,000,000**	**18,000,000**	**1,200,000**
Yearly maintenance costs per ground station	1,500,000	1,500,000	100,000
Number of ground stations required	3	30	40
Total ground station costs	**54,000,000**	**540,000,000**	**48,000,000**
Satellite build costs (per satellite)	140,000,000	25,000,000	140,000,000
Satellite launch cost (per satellite)	70,000,000	15,000,000	70,000,000
Project management cost per satellite (100 euro/ hour)	10,000,000	4,000,000	10,000,000
Total initial cost per satellite	**220,000,000**	**44,000,000**	**220,000,000**
Number of satellites required	3	88	2
Total satellite cost	**660,000,000**	**3,872,000,000**	**440,000,000**
Total system cost (satellites plus ground stations)	**714 million**	**4412 million**	**488 million**

C.6.4 Summary of airborne costs for the point-to-point technologies

C.6.4.1 The following tables summarise the airborne costs for the point-to-point technologies. A detailed description of the approach used in deriving these costs is given in Section C.4.

Costs in euro	**HFDL**	**VDL2**	**VDL3**	**VDL4** **Point-to-point**
Baseline assumed	HF voice or no HF	No CMU previously installed	CMU previously installed	CMU previously installed
Hardware				
Cost of transceiver	59,100	49,400	56,500	45,000
Antenna (x 2)	n/a	n/a	2,000	2,000
Upgrade of Radio Control Panel (RCP) x 2	n/a	n/a	19,000	N/a
Communications Management Unit (CMU)	n/a	47,000	n/a	N/a
Upgrade of Communications Management Unit (CMU)	n/a	n/a	8,000	8,000
Upgrade of Data Link Control Display Unit (DCDU)	n/a	n/a	6,000	N/a
Integration, installation & certification				
Installation kit(s)	2,955	4,820	4,275	3,325
Service bulletin	5,910	9,640	8,550	6,650
Man-hours (80 euro/hour)	2,955	4,820	4,575	3,325
Total initial costs per aircraft (1 transceiver)	**70,920**	**115,680**	**108,900**	**79,800**
Yearly maintenance costs per aircraft (1 transceiver)	5,910	9,640	9,150	6,650

Costs in euro	AMSS	NGSS	SDLS
Baseline assumption	n/a	n/a	n/a
Hardware			
Cost of transceiver	179,392	29,500	179,392
Integration, installation & certification			
Installation kit(s)	8,970	1,475	8,970
Service bulletin	17,939	2,950	17,939
Man-hours (80 euro/hour)	8,970	1,475	8,970
Total initial costs per aircraft (1 transceiver)	**215,270**	**35,400**	**215,270**
Yearly maintenance costs per aircraft (1 transceiver)	17,939	2,950	17,939

C.6.5 Summary of network and centre costs

C.6.5.1 The following table summarises the application specific network and centre costs.

	Cost in euro	Notes
Cost of an ATN network in Europe	**228 M**	[228]
Cost to provide ADD networks in Europe	**12 M**	(estimate – see Section C.5)
Cost to provide TIS-B server/processors and networks in Europe	**42 M**	(estimate – see Section C.5)
Cost to upgrade controller working positions in Europe	**680 M**	(estimate – see Section C.5)

C.7 Scenario costs

C.7.1 The following table evaluates the cost of each of the scenarios defined in Section 7, based on the cost summaries presented above. The costs have been NPVed using a discount factor of 8%.

C.7.2 Total cost includes traffic growth, maintenance and project lifetime to 2020 but does not include data costs.

C.7.3 Technology dependant costs exclude costs such as CWP enhancements and network costs which are common to all scenarios.

	Scenario							
	A	B	C	D	E	F	G	H
Total Cost	€ 31.1 Bn	€ 29.6 Bn	€ 27.9 Bn	€ 27.2 Bn	€ 29.3 Bn	€ 30.1 Bn	€ 31.7 Bn	€ 31.8 Bn
Technology Dependant Costs	€ 18.3 Bn	€ 16.8 Bn	€ 15.1 Bn	€ 14.5 Bn	€ 15.9 Bn	€ 16.7 Bn	€ 18.9 Bn	€ 19.0 Bn

D High Frequency Data Link

D.1 Introduction

D.1.1 High Frequency Data Link (HFDL) is a global end-to-end packet data communication system using High Frequency (3 to 30 MHz) bands of the radio spectrum assigned for aeronautical applications.

D.1.2 Due to the band of frequency used, the radio propagation characteristic varies depending on the local time of day (in relation with the amount of sunshine).

D.1.3 HFDL is designed to function as a subnetwork of the Aeronautical Telecommunications Network (ATN), and to provide a world-wide coverage based on operations at around 10 HFDL ground stations.

D.1.4 The use of HF and the wide coverage of each ground station (5000 km radius) imply a use of HFDL for the transmission of information data (not tactical, nor strategic) in oceanic and remote areas.

D.1.2 References

- HFDL SARPS, ICAO Annex 10, Volume III, Chapter 11, Amendment 74, 1999 [182].
- DO265, MOPS for Aeronautical Mobile High Frequency Data Link (HFDL) [71].
- DO 277, Minimum Aviation System Performance Standards (MASPS) for the High Frequency Data Link Operating in the Aeronautical Mobile (Route) Service (AM(R)S), March 2002 [183].
- SC-188, Minimum Aviation System Performance Standards (MASPS) for High Frequency Data Link (HFDL) [184].
- DO265, MOPS for Aeronautical Mobile High Frequency Data Link (HFDL), December 2000 [71].
- ARINC Characteristics 753 for HF Data Radio (HFDR) and HF Data Unit (HFDU) [185].

D.2 Technical Assessment

D.2.1 General Description

Parameter	Value	Notes
Service topology	Point-to-point	
ATN compliance	Yes	
Frequency band	HF spectrum: 2 to 32 MHz	System with 4 to 6 families of 5 to 6 HF frequencies each, based on operations at 8 to 10 HF Datalink ground stations for world wide coverage
RF Channels	Carrier centred at 1440 Hz and modulated at a 1800 Hz rate (symbol speed is always 1800 baud).	
Modulation scheme	M-PSK modulation	(2-PSK, 4-PSK or 8-PSK)
Bit rate	300, 600, 1200, or 1800 bps.	Four data rates are usable, based on signal quality, depending on the atmospheric conditions (impacting the SNR) :300, 600, 1200, and 1800 bps.
Channel access method	Reserved or random	Each slot can be designated either for uplink, for downlink for a particular aircraft (reserved slot) or for contention downlink (random access). Uses a protocol consisting of a combination of Frequency Division Multiple Access (FDMA) and Slotted Time Division Multiple Access (TDMA)
Frequency availability (allocation status)	Available	Band globally available.
Dependencies	Time-source	Each ground station needs a time reference for the proper working of its squitter. The access to the physical medium is a random access to avoid the collision as far as possible, and there is a need for temporal co-ordination in this procedure.

D.2.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Priority level management at the medium access layer compatible with ATN requirements.	At least two priority level are available (high and low).
Message length	32-seconds frame divided into 13 slots called a Squitter.	If we consider the 1.8 kbps throughput, each frame is 57.6 kb long, and each slot provides a 4.4 kb capacity.
Transmission delay	***Mean values:*** G/A all priorities: 28 sec A/G all priorities: 56 sec ***95 % values:*** G/A high priority: 51 sec A/G high priority: 146 sec G/A low priority: 66 sec A/G low priority: 252 sec	
Availability	Single HFDL system: 99 % Dual HFDL System: 99,9 %	Single ground station with a 5000 km radius with typically 70% availability
Integrity	Very High	Forward Error Coding Adaptive Channel Equalisation Interleaving End-to-end cyclic redundancy checks (16-bit CRC checksums)
Continuity of function	High	The ground system is highly redundant (3 stations in vision for one aircraft)
Capacity	130 aircraft for 3 ground stations	3 ground stations with 3 transmitters/ receivers each can provide service to 130 or more aircraft during the busiest hour with 99,3% availability.
Coverage (airspace category) & Range	All airspace categories (but intrinsically low-density areas) 19 ground stations provide global coverage Currently: 13 ground stations deployed Range 5000 km	Primary coverage is provided over a geographic radius of 5000 km from the station, with secondary coverage extending substantially further.
Priority management	2 priority levels on the medium access process.	These priority levels influence mainly the transmission delay (high and low priorities)

D.2.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status R&D Trials Pre-Operational Trials Operational Trials	Operational trials in progress	North Atlantic: Trials underway with Polar Air Cargo and NavCanada. Preliminary data reviewed at NATSPG/FIG, 25 Sep 2001. Continental Airlines participation following HFDR upgrade program Airbus: Airbus were scheduled to begin ATC validation trials in early 2002. Trials contingent upon red-label ATSU SW to allow for ATC via HFDL. Will use development aircraft (A340-600) to collect data during North Atlantic and North Polar trial flights. Data will be shared with JAA in support of ATC approval Japan (Japanese Civil Aviation Board): Japan Airlines and All Nippon Airways planning trials for 3Q2002
Standards Development		
ICAO	SARPS Published	ICAO Annex 10, Volume III, Chapter 11,
EUROCAE/RTCA	MASPS and MOPS published	DO 277, Minimum Aviation System Performance Standards (MASPS) for the High Frequency Data Link Operating in the Aeronautical Mobile (Route) Service ®(R)S), 03/2002 SC-188, Minimum Aviation System Performance Standards (MASPS) for High Frequency Data Link (HFDL) DO265, MOPS for Aeronautical Mobile High Frequency Data Link (HFDL), 12/2000
AEEC	Published	ARINC Characteristics 753 for HF Data Radio (HFDR) and HF Data Unit (HFDU)
ETSI	No activity	No activity is planned.
Other Standards	No activity	
Conclusion	Mature System	
Equipment Development		
Prototype airborne equipment status	Available	System already operational.
Red-label (operationally capable) airborne equipment status	Available	System already operational.

Certification	Available	Technology certified (protocol, avionics, ground equipment) Type Acceptance Approvals being applied for in England, France/Belgium, Germany, Switzerland, Italy,etc. FAA TSO Authorization received 25/07/97 FCC Type Acceptance approval 29/08/97
Conclusion	Mature System	
Prototype ground equipment status	Available	System already operational.
Operationally capable ground equipment status	Available	GLOBALink / HF Data Link service provided by ARINC with 13 ground stations with 200,000 messages per month sent.
Certification	No known issues	Operational system
Conclusion	Mature System	
System Deployment		
Ground deployment plans status	Significant	13 countries selected for Worldwide coverage; 8 agreements signed
Aircraft fleet equipment plans status	Significant	Aircraft equipped in 2000 (mostly US airlines): daily operation with all AOC application; ATC tests run by Transport Canada and Iceland CAA (25 flights per day) with 95% availability
Mandatory Carriage Status	No mandate planned	
Conclusion	Mature System	HFDL is supported globally by ARINC and is the only current datalink for North Polar routes.

D.2.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Airborne dedicated modem with HFDL protocol (the frequency band is specific to the system).
Ground architecture	Deployment of a global network of 19 dedicated stations assuring global coverage and high redundancy.

D.3 Cost Assessment

D.3.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of upgrading existing HF voice ground station equipment to HF voice/data	48,000	[163]
Installation	9,600	20% equipment cost
Total initial cost per ground station (1 transceiver)	**57,600**	
Yearly maintenance costs per ground station (1 transceiver)	4,800	10% initial hardware cost
Number of ground stations required	20	Estimate for worldwide coverage based on 13 already installed [225]
Cost for all ground stations (1 transceiver)	**1,152,000**	

D.3.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of replacing existing HF voice transceiver with HF voice/data transceiver (assumed use of existing antenna)	59,100	HW XK516D1 [217]
Integration, installation & certification		
Installation kit(s)	2,955	5% equipment cost
Service bulletin	5,910	10% equipment cost
Man-hours (80 euro/hour)	2,955	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**70,920**	
Yearly maintenance costs per aircraft (1 transceiver)	5,910	10% initial hardware cost

D.4 Industrial Assessment

D.4.1 Stakeholder Support

Stakeholder	Comments
General	Aircraft equipped in 2000 (mostly US airlines): daily operation with all AOC application; ATC tests run by Transport Canada and Iceland CAA (25 flights per day) with 95% availability
ARINC	HFDL forms part of the Globalink Service.
SITA	SITA has no plans to offer an HFDL Service.

D.4.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have airborne HFDL radios in production. According to Honeywell there are concerns over the availability performance of HFDL.
Rockwell Collins	Rockwell Collins have airborne HFDL radios in production. Several evolutions in HF Data link are underway and will be followed by Collins with the appropriate software update to the HF data radio. This happens in close coordination with ARINC and SITA, in order to avoid airborne equipment functions (and cost) for which there would be no service available

D.4.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	Mature system, available as buyer furnished equipment
Boeing	Mature system, available as buyer furnished equipment

D.5 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	World-wide coverage with few ground stations.
Summary of Weak Characteristics	The band of frequencies used for the signal propagation varies depending on the local time of day. Low throughput Delay performance insufficient to support ATC applications
Conclusion: feasibility, maturity & timescale	Global system available.

E Aeronautical Mobile Satellite Service (AMSS)

E.1 Introduction

E.1.1 The AMSS is a mobile communications system intended for provision of voice and data communications services to and from aircraft. The range of possible applications for these services include airline passenger communications (public correspondence), airline operations communications and air traffic control services.

System Configuration

E.1.2 The major elements of AMSS are:

- Space Segment: in particular the satellite communications transponders and associated frequency bands assigned for use by the Aeronautical Mobile Satellite System. The space segment uses transparent payloads.
- Aircraft Earth Stations (AES) which interface with the space segment (at L-band) for communications with Ground Earth Stations, and which interface in the aircraft with ACARS and other data equipment, and with crew and passenger voice equipment, in accordance with the relevant technical and operational requirements;
- Ground Earth Stations (GES): Which interface with the space segment (at C-band and L-band) and with the fixed networks, and which are operated in accordance with the relevant technical and operational requirements for communications with AESs; GESs operate to their own essentially independent but interlinked networks; and
- Network Coordination Stations (NCS): Located at designated earth stations, which interface via the space segment (at C-band and L-band) with the GESs for the purpose of allocating satellite channels.

AES Classes

E.1.3 AESs are classified according to their equipment configuration and capabilities, as follows:

- Class 1: Low gain antenna only, packet-mode data services only;
- Class 2: High gain or intermediate gain antenna, circuit-mode services only;
- Class 3: High gain or intermediate gain antenna, circuit-mode and packet-mode data services;
- Class 4: High gain or intermediate gain antenna, packet-mode data services only.

E.1.4 The nominal gain values for the two AES antenna types referenced above are:

- Low gain: 0 dBi;
- Intermediate gain: 6 dBi;
- High gain: 12 dBi.

AES Voice Services – Safety and Non-Safety

E.1.5 AESs supporting circuit-mode voice services (Classes 2 and 3) are classified according to the type of voice services that they can support, that is safety or non-safety. The Inmarsat safety/non-safety classification concerns only the minimum EIRP supported by the AES installation. This in turn reflects a theoretical voice channel return link availability that is expected for a particular AES.

E.1.6 AESs that comply with the minimum EIRP requirements for the safety classification are expected to provide a voice channel return link availability above 99% under worst case channel propagation conditions.

E.1.7 AESs that comply with the minimum EIRP requirements for the non-safety classification are expected to provide a voice channel return link availability above 95% under worst case channel propagation conditions.

E.1.8 It shall be noted that AESs which do not meet the minimum EIRP for the safety classification will not comply with the existing minimum EIRP requirements of ICAO SARPs or RTCA MOPS for voice services. The relaxed EIRP requirements for the non-safety classification are intended to meet the needs of those AES users wishing to carry aeronautical public correspondence circuit-mode traffic only, at the lower channel availability figure.

E.1.9 Both safety and non-safety AESs are fully compliant with the ITU International Radio Regulations criteria for the use of the AMSS band and provide for strict observance of the absolute priority which is required to be given to distress and urgency, ATS and AOC traffic over APC traffic.

Channel Types

E.1.10 The channels used for communications services and signalling between AESs and GESs are as follows:

- P-Channel: Packet mode time division multiplex (TDM) channel, used in the forward direction (ground-to-air) to carry signalling and user data. The transmission is continuous from each GES in the satellite network. A P-Channel being used for System Management functions is designated Psmc, while a P-Channel being used for other functions is designated Pd. The functional designations Psmc and Pd do not necessarily apply to separate physical channels.
- R-Channel: Random access (slotted Aloha) channel, used in the return direction (aircraft-to-ground) to carry some signalling and user data, specifically the initial signals of a transaction, typically request signals. An R-Channel being used for System Management functions is designated Rsmc, while an R-Channel being used for other functions is designated Rd. The functional designations Rsmc and Rd do not necessarily apply to separate physical channels.
- T-Channel: Reservation Time Division Multiple Access (TDMA) channel, used in the return direction only. The receiving GES reserves time slots for

transmissions requested by AESs, according to message length. The sending AES transmits the messages in the reserved time slots according to priority.

- C-Channel: Circuit-mode single channel per carrier (SCPC) voice channel, used in both forward and return directions. The use of the channel is controlled by assignment and release signalling at the start and end of each call.

AES Capabilities

E.1.11 Irrespective of its class, each AES is equipped with a capability to receive a medium rate forward P-Channel transmitted from a GES with a transmission rate of 600 bit/s and carrying signalling messages in packet form. Similarly each AES is equipped to transmit a return carrier in burst mode (R-channel) at a transmission rate switchable between 600 bit/s and 1200 bit/s. At log on the AES uses a transmission rate of 600 bit/s for transmission on the Rsmc channel. The GES responds on the Psmc at the same rate of 600 bit/s and indicates to the AES the Rd-channels and transmission rate to use (600 or 1200) for further transactions. The GES determines which transmission rate to command the AES to use dependent upon the satellite in use and the received signal quality of the log on request. This dual capability is required to take some advantage of the variations in aircraft antenna pattern and in spacecraft receiver sensitivity which may be encountered during a flight.

E.1.12 AESs in Classes 2 and 3 are also equipped with pairs of transmit/receive voice channel equipment (C-Channel). The number of voice channels equipped is at the discretion of the AES owner/operator.

E.1.13 The specific service capabilities of an AES will vary according to its Class and the number of channel units it has. Examples of typical installations would be:

- AES with one P-/R-/T-Channel unit, plus two voice channel units. This AES would support data and voice services simultaneously, with the voice and data using the same or different GESs. The data services (one GES) could include ATS, AOC and Administrative traffic. The voice services (several GESs) could provide flight crew, cabin crew and passenger communications, with urgent requirements pre-empting less important calls.

- AES with two P-/R-/T-Channel units, plus six voice channel units. This AES would support multiple data and voice services simultaneously. The data services could be to two different GESs, possibly one for ATS and another for AOC and Administrative traffic. The voice services could also use several GESs and could provide communications for flight crew, cabin crew and passenger. The need for urgent requirements to pre-empt less important calls would be small (although the capability would still be available).

- AES with a single P-/R-/T-Channel unit only. This AES would support data services only, to a single GES.

E.1.14 AESs in Classes 1, 3 and 4 also require additional protocol-oriented capabilities to support data services, providing error-free delivery of user messages with a high probability of success. These capabilities include provision of the T-Channel protocol using transmission bit rates the same as for the R-Channel.

E.1.15 AESs in Classes 1, 3 and 4 also have the option of being equipped with data channel equipment for higher bit rates, such as 2400 bit/s and 10,500 bit/s, to provide higher throughput and shorter message delays. These higher rates are entirely discretionary, and fitted only at the option of the AES owner/operator.

Future Services

E.1.16 Inmarsat have recently introduced the Swift64 high speed data link for cabin services (not ATM). This service should provide channels with up to 64 kbit/s, although in trials 46-57 kbps were obtained.

E.1.17 Honeywell and Thales have a prototype Inmarsat-approved Swift64 system which is due for production in 2003. The airborne system consists of a new HS-600 unit added on to a conventional Honeywell MCS-6000 Inmarsat system. The system is currently asynchronous, with 64 kbps (Swift64) data delivered to the aircraft and a Ku-band link for data delivery from the aircraft.

E.1.18 The next generation Inmarsat-4 satellites are due for launch next year. These satellites will be able to support broadband communications including 3G with channel rates in excess of 420 kbits/s.

E.2 References

E.2.1 The following key references define AMSS:

- ’System Definition Manual’, Inmarsat Maritime Safety Services, Version 2c July 1997 [186].
- Draft 8 of Supplement 10 to ARINC Characteristic 741, “Aviation Satellite Communication System, Part 1, Aircraft Installation Provisions” [169].
- Draft 3 of Supplement 7 to ARINC Characteristic 741, “Aviation Satellite Communications System, Part 2, System Design and Equipment Functional Description” [170].
- D-215A, Guidance on Aeronautical Mobile Satellite Service (AMSS) End-to End System Performance [92].
- D0-270, MASPS for the Aeronautical Mobile-Satellite (R) Service (AMS(R)S) as used in Aeronautical Data Links [93].
- DO-231 Design Guidelines and Recommended Standards for the Implementation and Use of AMS(R)S Voice Services in a Data Link Environment [91].
- DO-222, Guidelines on AMS(R)S Near-Term Voice Implementation and Utilization [90].
- Satellite Earth Stations and Systems (SES); Aircraft Earth Stations (AES) operating under the Aeronautical Mobile Satellite Service (AMSS)/Mobile Satellite Service (MSS) and/or the Aeronautical Mobile Satellite in Route Service (AMSIS/ Mobile Satellite Service (MSS), ETSI EN 301 473 v 1.2.2 February 2001 [187].

- Satellite Earth Stations and Systems (SES); Survey on the need for an ETS for Aircraft Earth Stations (AES) in the Aeronautical Mobile Satellite Service (AMSS), May 1996 [198].
- Honeywell and Thales receive Inmarsat Swift 64 High Speed Data Approval, Airfax2000, April 16th 2002 [250].

E.3 Technical Assessment

E.3.1 General Description

Parameter	Value	Notes
Service topology	Point-to-point	
ATN compliance	Yes	Only available with Data 3 mode.
Frequency band	Ka and L-band	Inmarsat uses only 3 MHz today. Service Link: Satellite to AES: 1544-1555 MHz AES to Satellite: 1645.5-1656.5 MHz Feeder Link: Satellite to GES: 3600-3620 MHz GES to Satellite: 6425-6440 MHz
RF Channels	C-Channel (Voice) P- R and T-Channel (Data)	
Modulation scheme	A-QPSK (Voice) A-BPSK (Data)	
Bit rate	21 kbps (Voice) 10.5 kbps (Data)	Lower data rate channels (600 and 1200 bps) used for Aero-L
Channel access method	TDMA and Random	Channel access is by random slotted ALOHA, GES then control channel using TDMA.
Frequency availability (allocation status)	Global allocation	
Dependencies	Ownership	The service depends on the INMARSAT satellite constellation with the exception of the Japan Civil aviation with MSAS system.

E.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Only offered through priority management in the slot allocation mechanism and pre-emption mode.	
Message length	Not Defined	Packet mode data is built up from 256 bit Protocol Data Units. There is no limit on overall size (M-bit processing).
Transmission delay	5-20 seconds	Earth station to satellite ~ 125 ms Indicative values for packet-mode data services (from RTCA simulations), considering the AES, space segment and the GES: to-aircraft: 5 sec (95% transfer delay for a 4.8 kbps channel and high priority services) from-aircraft: 20 sec (95% transfer delay for a 4.8 kbps channel and high priority services) No significant difference with higher bit rates (10.5 kbps for Aero-H equipment)
Availability	99.9% for one GES including antenna and radio equipment. 99.95% for the access control and signalling equipment, modems and terrestrial interface equipment.	Each satellite being connected to several GESs. Depending on the ground architecture retained the impact of GES failure should be reduced.
Integrity	10^{-6}	BER: 10^{-5} for packet data
Continuity of function	High	
Capacity	4800 bps /per channel	Max. throughput per a/c: is approximately 4800 bps using a 10500 bps channel rate
Coverage (airspace category) & Range	Near Global	High latitudes (above to 72°) are not covered
Priority management	Yes, 16 levels	In accordance with the ITU rules (AOC is also classified as safety related in comparison with public correspondence communications).

E.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Completed	Significant research undertaken in the 1980s, including the PRODAT studies for ESA.
R&D Trials	Completed	Demonstration of the DATA 3 mode for ADS C (ATN compliant) made during ADS Europe project in 1998
Pre-Operational Trials	Completed	
Operational Trials	Completed	FANS 1/A
Standards development		
ICAO	Published	Compliant with ICAO Annex 10, Volume III, Chapter 4, AMSS Standards and Recommended practices (SARPs) for Mobile Satellite Systems (MSS) in an AMSIS environment
EUROCAE/RTCA	Published	D-215A, Guidance on Aeronautical Mobile Satellite Service (AMSS) End-to End System Performance (Ref 92) D0-270, MASPS for the Aeronautical Mobile-Satellite (R) Service (AMS(R)S) as used in Aeronautical Data Links (Ref 93) DO-231 Design Guidelines and Recommended Standards for the Implementation and Use of AMS(R)S Voice Services in a Data Link Environment (Ref 91) DO-222, Guidelines on AMS(R)S Near-Term Voice Implementation and Utilization (Ref 90)
AEEC	Published	ARINC Characteristic 741 provides the Aircraft Installation Provisions as well as the System Design and Equipment Functional Description for the Aeronautical Mobile Satellite System (AMSS). The standard covers both voice (circuit mode) and data (packet mode DATA 2 and 3).
ETSI	Published	Satellite Earth Stations and Systems (SES); Aircraft Earth Stations (AES) operating under the Aeronautical Mobile Satellite Service (AMSS)/Mobile Satellite Service (MSS) and/or the Aeronautical Mobile Satellite in Route Service (AMSIS/ Mobile Satellite Service (MSS), ETSI EN 301 473 v 1.2.2 February 2001
Other Standards	Published	The INMARSAT SDM is a very detailed standard which enables AES and GES manufacturers to develop products.

Conclusion	Mature	No further development needed.
Equipment Development		
Prototype airborne equipment status	Available	Available since 1989.
Red-label (operationally capable) airborne equipment status	Available	Full world wide coverage by Inmarsat + coverage centred around Japan by JCAB
Certification	Complete	Airborne Certified Equipment is currently available on the market In flight operation certified (FANS 1 and A)
Conclusion	Operational System	
Prototype ground equipment status	Available	
Operationally capable ground equipment status	Available	Full world wide coverage by Inmarsat + coverage centred around Japan by JCAB
Certification	Completed	
Conclusion	Operational System	
System Deployment		
Ground deployment plans status	Significant	Ground and Space infrastructure maintained by Inmarsat. Services support by ARINC and SITA.
Aircraft fleet equipment plans status	Significant	2000+ equipped aircraft (majority of long haul) Airbus A340/330 and Boeing 747-400/777/767 are fitted with SATCOM avionics as baseline. Avionic implementation still too costly for non-oceanic operations.
Mandatory Carriage Status	No	No mandate is envisaged.
Conclusion	AMSS is an operational system	The communication system is currently supporting FANS 1 and A services (CPDLC and ADS C) in the ACARS mode (DATA 2).

E.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Avionics cost high even with the new AERO I mode (non active antenna).
Ground architecture	Limited number of GES (ground earth stations) under direct control of communication operators partners of Inmarsat.

E.4 Cost Assessment

E.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of a new AMSS ground station	15,000,000	[163]
Installation	3,000,000	20% equipment cost
Total initial cost per ground station	**18,000,000**	
Yearly maintenance costs per ground station	1,500,000	10% initial hardware cost
Number of ground stations required	3	[261]
Total ground station cost	**54,000,000**	
Satellite build costs (per satellite)	140,000,000	Inmarsat-4
Satellite launch cost (per satellite)	70,000,000	
Project management cost per satellite (100 euro/hour)	10,000,000	50,000 man hours
Total initial cost per satellite	**220,000,000**	
Number of satellites required	3	2 in orbit plus one spare [226]
Total satellite cost	**660,000,000**	
Total system cost (satellites plus ground stations)	**714,000,000**	

E.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of new AMSS satellite system avionics	179,392	Rockwell Collins AERO-I system (3 channel) SAT-2000-3 [218]
Integration, installation & certification		
Installation kit(s)	8,970	5% equipment cost
Service bulletin	17,939	10% equipment cost
Man-hours (80 euro/hour)	8,970	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**215,270**	
Yearly maintenance costs per aircraft (1 transceiver)	17,939	10% initial hardware cost

E.5 Industrial Assessment

E.5.1 Stakeholder Support

Stakeholder	Comments
ARINC	Provide both AOC and FANS-1/A services
SITA	SITA already provides global INMARSAT coverage via GES in France and Australia operated by France Telecom and Xantic respectively. The Satellite AIRCOM Service (under which the AMSS service is marketed) is compliant with the ATN and was extensively used in the ADS Europe trials. Furthermore, both the VHF and Satellite services are used extensively to support FANS 1/A operations in oceanic and remote terrestrial airspace and the trend is that this service will continue to grow globally in proportion to the increasing numbers of FANS 1/A aircraft. SITA supports AMSS services for over 2000 aircraft.
ANSPs	Several ANSPs use FANS1/A services, NATS use satcom in NAT.

E.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have equipment in production. Several new systems are available to accommodate Inmarsat's recently activated Aero-I, or spot beam, service. And future updates to support the next generation of high-speed data and anticipated LEO/MEO services are being planned. The current efforts are focussed on evaluating these emerging systems for their potential to support the requirements associated with aeronautical safety services, necessary for ATS datalink applications. New developments are B/ Inmarsat Aero-I, Aero-H, Aero-H+. Honeywell and Thales have developed Inmarsat Swift64 airborne equipment. They have a prototype Inmarsat-approved Swift64 system which is due for production in 1st quarter 2003. The airborne system consists of a new HS-600 unit added on to a conventional Honeywell MCS-6000 Inmarsat system.
Rockwell Collins	Rockwell Collins has Aero I, Aero H and Aero H+ compatible SatCom equipment in production. Collins' High Speed Data SatCom evolution is currently becoming available concurrent with Inmarsat's 64Kb/s services. Collins makes HSD modules available to convert the basic ARINC 741 SAT-906 SatCom to high speed SatCom, consistent with Inmarsat's available service level.
Thales Avionics	Inmarsat equipment in production, including a Honeywell/Thales Inmarsat Swift64 airborne system.

E.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	Airbus A340/330 fitted with Satcom avionics as a baseline.
Boeing	Boeing supplies ARINC-741 compatible satcom systems with their aircraft. The Boeing airframes 747-400/777/767 are fitted with Satcom avionics as a baseline.

E.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Operational Used world-wide Wide range of certified equipment on the market Existing system and existing service providers. A significant number of long haul aircraft are equipped of SATCOM avionics.
Summary of Weak Characteristics	Low throughput Communication service is expensive Communication services costs quite high due to the monopoly of Inmarsat. Other service providers could enter the market, but start-up costs are high. The Japanese CAA may offer AMSS services suing MTSAT. Cost of avionics still too high for non oceanic areas. QoS not adapted to continental area CPDLC services.
Conclusion: feasibility, maturity & timescale	Service available System not adapted to continental busy area like Europe. No plan yet revealed on the usage of such system to support ATM safety related communication services. Cost of avionics high. System not designed to serve the needs of ATM safety related communications. Existing system and existing service in the USA CONUS for passenger and private jet. Market competition in the IFE (In Flight Entertainment) could be a good opportunity for the deployment of such system on board commercial and private aircraft. Could be used within limitations for some specific non-safety-critical ATM communication services with the benefit to capitalise on the investment made for IFE (adaptation necessary needs to be funded).

F VDL Mode 2

F.1 Introduction

F.1.1 VDL Mode 2 (VDL2) provides an air/ground bit-oriented point-to-point VHF data link which is compatible with the ATN. VDL2 is designed to support both AOC and ATS applications, and for many airlines is seen as an upgrade to ACARS for their AOC communications needs.

F.1.2 Airlines and the data link service providers ARINC and SITA are pushing ahead with an initial implementation of VDL2 which uses VDL2 as an improved carrier for the ACARS service. This is termed ACARS over AVLC (AOA).

F.1.3 Eurocontrol has progressed the VDL2 system for use for ATS applications under the PETAL II, Euro VDL2, and Link 2000+ programmes.

F.1.4 The Link 2000+ programme is currently ongoing and aims to use VDL2 to support initial data link services such as:

- Data Link Initiation Capability
- Digital ATIS
- ATC Communication Management.

F.1.5 ATC Clearances and Flight Plan Consistency are also planned to be progressively introduced in the en-route environment in a second phase of the Link 2000+ programme.

F.1.6 The aim of the Preliminary Eurocontrol Test of Air/ground data Link (PETAL) II trials, which have now completed, were to conduct air/ground data link operational trials using multiple data link-equipped aircraft on the same voice R/T channel, during routine ATC operations, in order to develop the CPDLC data link application toward full operational use through real time operations exposure.

F.1.7 The EuroVDL2 project, which is currently ongoing, aims at defining and validating elements required for the implementation of VDL2 within the European States.

System description

F.1.8 VDL2 uses a Differential 8-Phase Shift Keying (D8PSK) modulation scheme. The D8PSK modulation scheme, which is the same as that used by VDL3, was selected by ICAO AMCP to avoid the multiplication of different Air/Ground modulation schemes.

F.1.9 The D8PSK modulation scheme encodes binary data as change in the phase of the VHF signal. It is called 8-PSK because there are 8 possible levels of change in phase between each symbol. The 8 possibilities enable each symbol to encode the value of 3 bits.

F.1.10 The VDL D8PSK scheme specifies the transmission of 10,500 symbols per second which at 3 bits per symbol gives a data rates of 31.5 kbits per second.

F.1.11 VDL2 uses a CSMA medium access protocol (Collision Sensitive Multiple Access) similar to the VHF ACARS scheme. One VHF channel is shared by many aircraft and ground stations.

Effective Data Rate

F.1.12 The estimated data rate from ST15 [2] is 5355 bps, and is based on an estimation which the study team have not been able to inspect. It has been included by the study team for consistency with other assessments. It corresponds to the data rate used in the Link2000+ CAP assessment [245] and applied to a service volume consisting of all aircraft within line of sight – 230 NM.

F.1.13 Reference [246][22] describes work carried out by ARINC for Eurocontrol as part of the development of an ATN simulator. In that work, they developed a simulator of the VDL2 protocol, validated against various theoretical calculations and then applied it to three scenarios:

- An airport scenario where there is no overlapping coverage with other stations
- A terminal scenario where there is a small amount of overlapping coverage
- An en-route scenario where there is significant overlapping coverage - the details of which would vary from scenario to scenario but which, in the study for Eurocontrol, was based on the Eastern Seaboard of the US.

F.1.14 The performance results obtained are critically dependent on the target probability of transmission success. ARINC argued that a value of 0.9 was acceptable so as to result in the possibility of a retry giving an overall latency of less than 2 seconds.

F.1.15 The results are quoted in parameters that were focussed on the study objective (i.e. they need some conversion to compare with this study's results). This has been done this for a message with a user data size of 249 octets. The results indicate that the bit rates obtained are:

Homogenous Zone	**Effective Data Rate**
Airport	9734 bps
Terminal	3454 bps
En-route	1200 bps

F.1.16 The high rate for the airport environment would be obtainable assuming a separate airport channel. Similarly for the terminal environment. It would not be right to assume that the rates apply if a single channel is used. The rates would be more likely to be closer to the en-route figures.

F.1.17 The coverage volume for the en-route results is assumed to be 150 nmi. Scaling this against the line of sight assumption used in the CAP report, results in (230/150)^2 * 1200 = 2800 bps in the en-route case.

F.1.18 The study team did a simplified simulation analysis of VDL2 to investigate the effects of overlapping coverage. For a scenario in which a ground station enjoys

[22] Comments received from ARINC indicate that this work should no longer be considered valid as it did not allow for improvements in data rate due to FEC. ARINC provided an estimate of the throughput as 12000 – 14000 bps based on operational experience and recent trials. This value therefore does not consider the impact of representative load on effect data rate and is consistent with the calculations presented above.

unique coverage for half of its coverage volume, and shared coverage for the other half, we obtained a data rate of 3000 bps for VDL2, well in line with the ARINC simulations. A similar level of agreement was obtained in a scenario with no overlapping coverage (i.e. the airport scenario), where the simplified simulation results gave a data rate of 9000 bps.

F.1.19 The study team conclude that if a separate channel is used for airports, it is justified to use a higher data rate than that used by the CAP study. A rate of 9000 bps would be suitable. A separate channel for en-route/terminal is more likely to provide a data rate of 3000 bps over the line of sight coverage volume. Mixing airport and en-route coverage on a single channel is a bad idea and likely to ruin the airport region performance.

F.1.20 The conclusion is that the 5355 figure developed by ST15 should not be used. In the main analysis the following figures have been used:

Homogenous Zone	**Effective Data Rate**
Airport	9734 bps
Terminal	3454 bps
En-route	2800 bps

F.1.21 The study team notes that both ARINC and SITA have rejected this figure,, but have not yet provided any evidence for a higher figure based on realistic loads. SITA provided a comment that

”VDL2 channel will provide 10 times the capacity of the existing VHF ACARS channel, i.e. for Europe, where approximately 7 million kilobits are exchanged monthly today over 3 VHF channels, the effective capacity will be increased to 70 million kilobits which SITA believes will more than adequately meet foreseen increases in AOC communications as well as the requirements for ATS applications. If the number of channels is increased from 3 to 6 this would effectively double the capacity, i.e. enable the exchange of 140 million kilobits per month”.

F.1.22 It is noted that the normally claimed effective data rate for VHF ACARS is 300 bps.

F.1.23 The study team are concerned by the lack of agreement on this figure and ware that Eurocontrol are developing simulation tools to resolve the issue. This analysis needs to be re-addressed when results from these simulations are known.

Spectrum

F.1.24 VDL2 is planned to operate in the VHF Aeronautical COM band. Interference testing of VDL2 to assess frequency compatibility with other onboard systems has been carried out by Eurocontrol and is now complete. Eurocontrol has progressed frequency planning at recent ICAO FMG meetings, and has specified a number of steps to vacate the necessary frequency channels.

F.1.25 According to the Eurocontrol plan presented at FMG, in Europe VDL2 is planned to operate in four frequencies at the top of the COM band: 136.975, 136.925, 136.875, and 136.825 MHz. This involves clearing existing users of the channels away from these channels, and into other channels lower in the spectrum.

F.1.26 The figure below shows the possible steps as outlined in the Eurocontrol plan: as the current situation (labelled 2001), a possible intermediate step (middle column), and the channels as they could be in 2010 (right column).

VHF Channels (MHz)	(2001)	possible step	2010
136.625	ATS	ATS	ATS
136.650	ATS	ATS	ATS
136.675	ATS	ATS	ATS
136.700	ATS	GB	GB
136.725	ATS	VDL4	VDL4
136.750	ATS	GB	GB
136.775	ATS	GB	VDL4
136.800	OPC	GB	GB
136.825	OPC	ACARS a	VDL2
136.850	OPC	GB	GB
136.875	OPC	GB	VDL2
136.900	ACARS s	ACARS s	GB
136.925	ACARS a	GB	VDL2
136.950	Exp VDL4	GB	GB
136.975	VDL2	VDL2	VDL2

ATS :Protected Air traffic Services (voice)
ACARS s : SITA ACARS
ACARS a : ARINC ACARS
OPC : Operational Communications (Airlines voice channels)
GB : Guard Band channel

Figure F-1: Proposed Eurocontrol frequency plan for the EUR region

Demonstration

F.1.27 Eurocontrol conducted VDL2 trials as part of the PETAL II and EuroVDL2 programmes. PETAL-II demonstrated ATS operations using ATN communications over VDL-2 subnetworks using 6 ARINC VDL2 ground stations and 4 American Airlines aircraft equipped with a Level D certified Collins CMU. EuroVDL is testing ATN communications over VDL-2 sub-networks using SITA VDL2 ground stations and a QinetiQ lab aircraft.

F.1.28 In 2001 PETAL II-e flights were operated over Europe by American Airlines planes pioneering controller-to-pilot datalink exchanges over an implementation of VDL2/ATN. The VDL2/ATN ground infrastructure was deployed by ARINC and the avionics developed by Rockwell Collins.

F.1.29 Among others, those flights have delivered observations related to VDL2 functions. The algorithm applied to maintain an efficient VDL2 air-ground connection with the overflow ground-stations is subject to corrections and improvements. The PETAL-II report includes in an appendix a list of the problems that were observed during the trials.

F.1.30 Currently, more flights are taking place in Europe operating the same CPDLC, ATN and VDL2 functions. This time the ground network used belongs to SITA, and the same avionics is integrated in a QINETIQ lab aircraft.

F.1.31 The FAA Build 1 programme implements air-ground data-link communications (VDL2/ATN) through the ARINC VDL2 subnetwork. Sixteen commercial aircraft have been equipped with Rockwell Collins VDL2 CMU for American Airlines. It should be noted that Delta Airlines has committed four Boeing 767-400 aircraft for Trial participation which will be equipped with the Teledyne ARINC 758 Communications Management Unit (CMU) and 750 VHF Data Radio (VDR) package.

Airborne and ground terminal design

F.1.32 To use VDL2, an aircraft must be equipped with:

- VHF Data Radio (VDR) transceiver
- Antenna
- Communications Management Unit/Air Traffic Service Unit (CMU/ATSU).

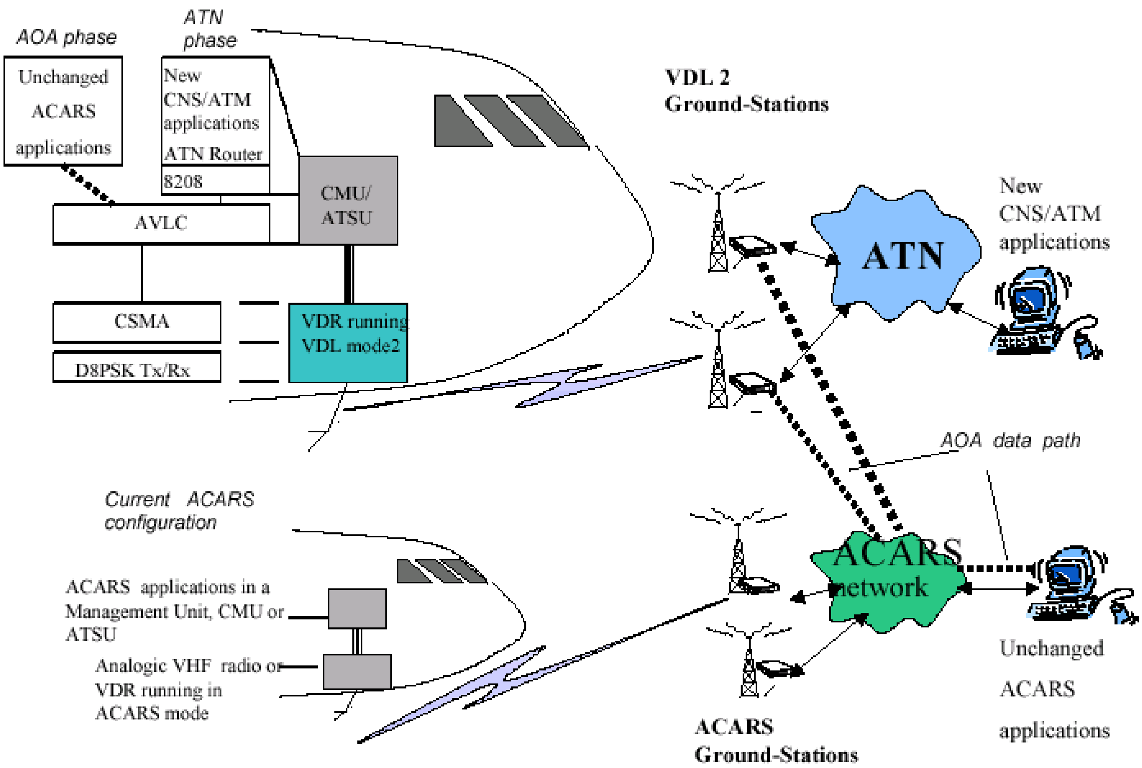


Figure F-2: Network migration from ACARS to VDL2

F.2 VDL2 is designed to improve on the existing ACARS system. During the implementation of VDL2, the ground station networks for VDL2 and for ACARS will co-exist for some time, and there will be aircraft using VDL2 as well as aircraft using ACARS.

F.1.1 Figure F-2 shows how the migration from ACARS to VDL2 will take place.

Operation

F.1.2 SITA and ARINC have plans to deploy a ground VDL2 infrastructure (60-80 units for SITA) that will cover all Europe. ARINC advertises in 2002 that it has already installed VDL2 ground stations in 110 sites across the US, and at three sites providing coverage across southern France.

F.1.3 In addition, the LINK 2000+ Programme objective is to plan and co-ordinate the implementation of operational air/ground data link services for Air Traffic Management (ATM) in the core area of Europe in the timeframe 2000 – 2007. Thus while ARINC and SITA develop the ground infrastructure (for AOA and ATN), the Eurocontrol programmes are implementing the ATS data link services.

F.2 References

F.2.1 The following key references define VDL2:

- Standards and Recommended Practices (SARPs) for VHF Digital Link, Annex 10, Volume III, Part I, ICAO [33].
- Draft Manual on Detailed Technical Specifications for the VDL Mode 2 Digital Link [34].
- ED-92: Minimum Operational Performance Specification for an Airborne VDL Mode-2 Transceiver Operating in the frequency range 118-136.975 MHz [79].
- VHF air-ground Digital Link (VDL) Mode 2; Technical characteristics and methods of measurement for ground-based equipment; Part 1: Physical layer, EN 301 841-1 (published), Part 2: Data link layer, EN 301 841-2 (draft), ETSI, 2002 [167].
- LINK 2000+ Programme Master Plan, Version 0.94 [20].
- Euro VDL Mode 2 – Project Overview, Version 2.0 [32].
- 631-3 VHF Digital Link Implementation Provisions Functional Description, October 2000, ARINC [171].
- Eurocontrol VDL-2 day presentations,18th April 2001 [172].
- VDL-2 Physical layer validation report, Eurocontrol COM -5-11-0501 [173].
- PETAL-II Transition and Final Report, Volume 1, Eurocontrol, May 2002 [207].
- PETAL-II Transition and Final Report, Volume 2, Eurocontrol, May 2002 [208].

F.3 Technical Assessment

F.3.1 General Description

Parameter	Value	Notes
Service topology	Point-to-point	Support for broadcast DLS addresses is mandatory, and support for broadcast DLS connection establishment is optional.
ATN compliance	Yes	
Frequency band	118.000 MHz – 136.975 MHz	Potential for 720 channels. A common signalling channel is allocated worldwide at 136.975 MHz
RF Channels	25kHz channels	
Modulation scheme	D8PSK	D8PSK at 10.5 symbols/s
Bit rate	31.5 kbits per second	
Channel access method	p-persistence CSMA-CD	Carrier Sense Multiple Access with Collision Detection
Frequency availability (allocation status)	Currently only the CSC (136.975 MHz) is dedicated to VDL-2. Expected that 4 frequencies will be dedicated to VDL-2 (136.975, 136.925, 136.875, 136.825).	This band is completely saturated in the western part of Europe making the allocation of channels difficult in the near future. Some services used locally by some airports or ACCs shall be moved from the 136.7MHz, 136.725 MHz and 136.750 MHz frequencies (in France, Germany, Sweden, Italy). SITA is granted licences for Amsterdam and CDG airports on the CSC frequency.
Dependencies	Airborne VDR supporting VDL2 frame transmission. Ground VHF Data Radio stations deployed by the Air/ground communication service provider.	Avionics implementation is specific: the physical and MAC layer are implemented in the radio (VDR) while the other layers (LME and above) are implemented in the CMU/ATSU hosting all the communication stacks (ATN router and application services).

F.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	No	No mechanism implemented at the sub network level.
Message length	Fixed length packet, allows fragmentation	VDL2 manages the packet fragmentation when the data to transmit are longer then the max packet size. So there are no upper-layer fragmentation headers to be added.
Transmission delay	Transit delay for TPDU (Transport Data Units), and for 95% of the time: - Uplink: between 0.4 s and 1.4 s. - Downlink: between 0.4 s and 0.9 s.	The transmission delay figures are trial results obtained under different channel load. There is no published result for Transmission delay. Value depends on the packet size and the compression ratio: better compression gives lower transit delay. Value is dependant on channel load.
Availability	About 99.9935 % for a single VDL2 equipment	For VDL2 Subnetwork: About 99.999% for CAA owned sub-network About 99.998% for a Service Provider sub-network
Integrity	BER design criteria is 10^{-3} 10^{-6} undetected after FEC mechanism	Use of Forward Error Correction field permits automatic correction of up to three octets in a 249 octets data block. The FEC assures that all corrupted frames are detected and discarded.
Continuity of function		
Capacity	3000 bps	This value has been obtained within the study and is disputed by ARINC and SITA. Eurocontrol are actively studying this issue and expect to report results in 2003.
Coverage (airspace category) & Range	Uplink coverage: - at FL240, 150 NM - at FL180, 120 NM - at FL140, 105 NM - at FL120, 90 NM. Downlink coverage: - At FL250, 135 NM	ARINC announces the coverage to be: - at FL250, 200 NM ARINC and SITA ground stations will cover most of the west-European countries.
Priority management	No	No mechanism at the sub network level.

F.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Limited	Eurocontrol have published a physical layer validation report [247] and a simulation performed by ARINC [246] but no large scale simulation of actual traffic has been performed. Such a simulation is urgently needed to determine the number of channels needed.
R&D Trials	Partially completed	The ACI RRI VDL-2 compliant Airborne ATN router prototype is currently under development. The Sofreavia ProATN Air/Ground ATN router is compliant with VDL-2 subnetwork. A demonstration license is currently in use at SITA for validation of their future ATN/VDL-2 service infrastructure.
Pre-Operational Trials	Partially completed	Eurocontrol are conducting VDL2 trials. PETAL-II trials are tested ATN communications over VDL-2 subnetworks (6 ARINC VDL ground stations, and 4 American Airlines aircraft equipped with Level D certified Collins CMU).
Operational Trials	Partially completed	SITA and ARINC have their own operational trials programmes
Operational Status	VDL2 is an operational system	AOA has been operational in the US since 4Q2000. More than 30 aircraft use the US system, sending over 80,000 messages monthly. FAA Build 1 programme entered initial daily use Oct 2002. It implemented air-ground datalink communications (VDL2/ATN) through the ARINC VDL2 network. Sixteen American Airlines aircraft are currently equipped with Rockwell Collins VDL2 CMU. Delta Airlines has committed four Boeing 767-400 aircraft for CPDLC Build 1 participation on 2003 which will be equipped with the Teledyne ARINC 758 CMU and ARINC 750 VHF Data Radio Package. Lufthansa and SAS have committed 20 aircraft each to the Link2000+ programme.
Standards Development		

ICAO	ICAO SARPS published.	Standards and Recommended Practices (SARPs) for VHF Digital Link, Annex 10, Volume III, Part I, ICAO ICAO Manual on Detailed Technical Specifications for VHF Digital Link Mode 2.
EUROCAE/RTCA	MASPS published RTCA MOPS published	RTCA SC-172: DO-224A VDL MASPS. EUROCAE (ED 92) for ATN RTCA SC-172: DO-281, MOPS for Aircraft VDL Mode 2 Physical, Link and Network Layer under draft
AEEC	AEEC standards published	AEEC ARINC characteristics 750. AEEC ARINC specification 631. AEEC ARINC specification 618 (for AOA).
ETSI	EN 301 841-1 (Part 1: physical layer) published EN 301 841-2 (Part2: Data Link layer): mature draft	ETSI RP05-STF148: EN 301 841 part 1 (released in 200/01), and part 2 (to be released end of 2003).
Other Standards	None	
Conclusion	Mature	
Equipment Development		
Prototype airborne equipment status	Available	Thales implements an airborne VDL-2 prototype system. Thales airborne EVR750 VDR has been used with a prototype AVLC software during Eurocontrol AVLC validation flight trials. It will be integrated with the RRI VDL-2 ATN software.
Red-label (operationally capable) airborne equipment status	Available	Rockwell Collins airborne CMU-900 interfacing a VHF-920/900(B) VDR Honeywell have a VDL2 transceiver available for the AT market. A transceiver for the GA market is expected in 3rd quarter 2003.

Certification	Some certified airborne equipment	Rockwell Collins has already certified a VDL2 equipment suite for VDL2/AOA and ATN (VDR + CMU). Other manufacturers are testing and certifying now for VDL2/AOA (e.g. Airbus, Honeywell). Rockwell Collins airborne CMU-900 interfacing a VHF-920/900(B) VDR, is certified at lease level D now, and should be certified level C for Build 1. After A320, Airbus Industries plan to certify a VDL2/ATN airborne equipment that is SARPs compliant DO178-B Level C. However, the product launch depends upon market opportunities.
Conclusion	Mature	
Prototype ground equipment status	Available	
Operationally capable ground equipment status	Available	Télérad has a ground VDR (9000 series) commercially available that is compliant with VDL-2 standards. FAA declared their service operational (Initial Daily Use) in October 2002. ARINCs AOA network was declared operational on November 20, 2000; the ATN component for FAA CPDLC Build 1 was declared operational September 30, 2002
Certification	No known issues	
Conclusion	Mature operational system	
System Deployment		

Ground deployment plans status	Significant	SITA and ARINC are deploy a ground infrastructure (60-80 units for SITA) that will cover all Europe. A summary of the ARINC coverage plans is as follows: Europe: Three stations installed in France for AIRBUS testing and operational service, further deployment will be based on customer requirement and consultation with Eurocontrol Link2000+ programme. Almost all 107 ground stations currently deployed in Europe for POA (plain old ACARS) service are easily upgradeable to support POA and VDL2 (AOA and ATN). North America: Currently 110 stations deployed with the CONUS areas with 50 more planned for this year to complete the en-route and terminal coverage. Japan: ARINC has been selected by AVICOM Japan to provide a complete VDL2 network for Japanese airspace. This will be completed by September 2003. SITA also have plans to deploy VDL2 globally
Aircraft fleet equipment plans status	Limited at present	Airlines are expected to equip when ground infrastructure is in place. DLH has declared migration of ACARS fleet to VDL2/AOA with first 15 aircraft this year.
Mandatory Carriage Status	None	No mandate is currently envisaged, but Airbus states that one could be beneficial in medium term, as this would reduce the overall unit equipage costs.
Conclusion	Mature Operational System	

F.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Depends on the implemented applications, and on the communication stack (ATN or AOA). VDL2 is intended as the successor of ACARS and will use the same antenna and radio location.
Ground architecture	For ACARS AOC communications utilizing the ATN, a GACS gateway will be necessary (implemented by the service provider). SITA and ARINC provide two different ground architectures.

F.4 Cost Assessment

F.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of VDL2 ground station	60,000	Reference [232] gave cost including installation
Installation	12,000	20% equipment cost
Total initial cost per ground station (1 transceiver)	**72,000**	
Yearly maintenance costs per ground station (1 transceiver)	6,000	10% initial hardware cost
Number of ground stations required	150	
Total ground station cost (1 transceiver)	**10,800,000**	

The costs provided assume that the ANSP provided the infrastructure. This does not have to be the case. Both ARINC and SITA are deploying VDL2 infrastructure which can support ATS communications. An ANSP may decide to use these networks on a service usage or access basis hence reducing the need for capital outlay. The overall cost can be spread across the entire user base (ATS and AOC).

It is also noted that existing POA ground stations can be upgraded to VDL2 at a fraction of the costs quoted (ARINC).

F.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of upgrade of existing ACARS transceiver (use of existing antenna)	49,400	Estimate from [38]
Communications Management Unit (CMU)	47,000	[218]
Integration, installation & certification		
Installation kit(s)	4,820	5% equipment cost
Service bulletin	9,640	10% equipment cost
Man-hours (80 euro/hour)	4,820	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**115,680**	
Yearly maintenance costs per aircraft (1 transceiver)	9,640	10% initial hardware cost

F.5 Industrial Assessment

F.5.1 Stakeholder Support

Stakeholder	Comments
Eurocontrol	Link2000+
FAA	CPDLC Build 1 trials
American Airlines	16 aircraft with Rockwell Collins equipment (AOA/ATN)
Continental	6 aircraft with Rockwell Collins (AOA)
Delta	AOA/ATN Equipage planned for Q2/2003 Teledyne
South West	Complete fleet wide equipage with VDL2. South West never equipped with POA and they are going straight to VDL2.
USAF	Equipping KC-135, C-17, KC-10, C-5 and C21 fleets.
ARINC	ARINC have plans to support VDL2 globally.
CANSO	CANSO have recommended that ANS Providers having a requirement for VHF-based line of sight datalink system adopt, as a minimum, VDL2 for use during the period 2003-2012. [262]

Stakeholder	Comments
SITA	The SITA AIRCOM Datalink Service today comprises over 650 VHF ACARS stations deployed in over 165 countries The SITA VHF AIRCOM Datalink service has over 120 airlines/aircraft operator customers which have over 5,000 VHF ACARS equipped aircraft that use the service on an almost daily basis, exchanging on average 11.5 million kilobits per month. Over sixty percent of this traffic is exchanged over the European region where the service operates on 3 frequency channels. Over 2,000 (representing seventy customers) of these aircraft are also equipped with SATCOM avionics that exchange, on average, over 2 million kilobits per month. Since the early 1990's an increasing number of air traffic service providers have started to use the AIRCOM Datalink service to exchange Air Traffic Service related application data which currently accounts for around 5% of the total traffic exchanged over the service. SITA is fully committed to supporting the cost-effective implementation of the ICAO CNS/ATM system and has made significant contributions to both the ICAO ATN and AMCP Panels that have defined the technical standards for ATN and VDL technology. Furthermore, SITA actively supports and contributes to both ICAO and IATA regional planning and implementation groups that are focusing on CNS/ATM implementation. In Europe, SITA is a member of the Eurocontrol Link2000+ Programme Steering Group that is overseeing and co-ordinating the implementation of CPDLC services in Europe. The Link2000+ Programme is the first European wide programme that will introduce ATS Datalink applications. To date the programme has the commitment of two major airlines, Lufthansa and SAS who have both committed to upgrading 20 aircraft each with CPDLC/ATN/VDL2 capable avionics by end 2004. On the ground side, Maastricht UACC has committed to the introduction of CPDLC services over the ATN/VDL2 infrastructure by mid 2003.Furthermore, both of these airlines have made decisions to equip their entire fleets with VDL2/AOA avionics. It is expected that the LH fleet upgrade will be completed by 2006/7 and the SAS upgrade by 2010. A VDL2 channel will provide 10 times the capacity of the existing VHF ACARS channel, i.e. for Europe, where approximately 7 million kilobits are exchanged monthly today over 3 VHF channels, the effective capacity will be increased to 70 million kilobits which SITA believes will more than adequately meet foreseen increases in AOC communications as well as the requirements for ATS applications. If the number of channels is increased from 3 to 6 this would effectively double the capacity, i.e. enable the exchange of 140 million kilobits per month.
ARINC	ARINC have plans to support VDL Globally.
Lufthansa	Lufthansa have been announced as a Link2000+ 'Pioneer'. They will equip 20 aircraft for VDL2/ATN. The whole fleet will be equipped with VDL2/AOA.

F.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell currently have a VDL2 transceiver available for the AT market. A transceiver for the GA market is expected in 3rd quarter 2003.
Rockwell Collins	Rockwell Collins VDL-2 data radios, as well as the router functions (CMU-900) are in production. VDL-2 requires several components, including the VDR, the pertinent airborne communication management unit functions, as well as the service (provided by SITA, ARINC). Collins has participated in several VDL-2 demonstration programs, including FAA and Eurocontrol (PETAL) trials.
ACI	The ACI RRI VDL-2 compliant Airborne ATN router prototype is currently under development.
Sofreavia	The Sofreavia ProATN Air/Ground ATN router is compliant with VDL-2 subnetwork. A demonstration license is currently in use at SITA for validation of their future ATN/VDL-2 service infrastructure.

F.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	Airbus have a software upgrade for existing aircraft to provide both VDL2/AOA and VDL2/ATN capabilities. Airbus anticipate that all aircraft could be equipped by 2010.
Boeing	Boeing are currently delivering VDL2 equipment with every model of the 747 airframe.

F.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Effective data rate is ten times that of the existing VHF ACARS system. System foreseen to be the successor of ACARS for the support of AOC traffic and could be the first ATN sub network for good synergy. AOA mode could reuse the existing AOC applications without the need to redevelop them. Strong support to use VDL2 as the prime enabler for ATN compliant data link due to the AOC usage of VDL2 making the investment more productive.
Summary of Weak Characteristics	Under load conditions, effective data rate is estimated as 3000 bps. No prioritisation; QoS is not managed in the system, limiting the scope of services that could be accommodated on VDL2. Absolute message delivery times not guaranteed, but mean and 95^{th} percentile times are guaranteed by service provider No coverage for oceanic or remote airspace, as the range of each station is limited. Service providers (SITA and ARINC) will get the market, making it difficult for ATSPs to enter it.
Conclusion: feasibility, maturity & timescale	VDL2 is now operational in Europe and North America, with mature plans for increasing coverage and fleet equipage. VDL2 is ready to support Step 1 applications as and when they are implemented. Ground infrastructure deployment and operational service set-up could be ready within less than one year. VDL2 is not designed to support time critical ATS services.

G 1090 MHz Extended Squitter

G.1 Introduction

G.1.1 The 1090 MHz Extended Squitter (1090 ES) is an extension of Mode S technology. A number of extended squitters are transmitted at a high rate (five times a second). Each message consists of 112 bits, 24 bits of which are used for parity. The data rate used is one megabit per second, within a message. Access to the 1090 MHz channel is randomised, and the channel is shared with Secondary Surveillance Radar (Mode A/C and Mode S) and Traffic Alert and Collision Avoidance System (TCAS).

G.1.2 1090 ES provides air-air, air-ground and ground-air broadcast services. A complementary uplink broadcast service could be provided at 1030 MHz which is the Mode S interrogation frequency.

G.1.3 1090 ES enjoys support from the FAA and some European ANSPs. Support in Europe is considered ‘medium’.

G.1.4 The risk in developing 1090 ES in to a operational system is considered low. Certifiable equipment already exists which is very close to the anticipated final requirements for 1090 ES.

G.1.5 For air-air surveillance 1090 ES could be used in all airspace types. For air-ground surveillance, 1090 ES requires a relatively high density of ground stations and is therefore not suitable for oceanic and remote areas.

G.1.6 The coverage available from a 1090 ES ground stations is very dependent upon the density of traffic and local deployment of other systems (TCAS, Mode S) operating in the same frequencies.

G.1.7 The modulation of the ADS-B message transmission is Pulse Position Modulation (PPM).

Airborne terminal design

G.1.8 The layout of the airborne 1090 ES system is illustrated below.

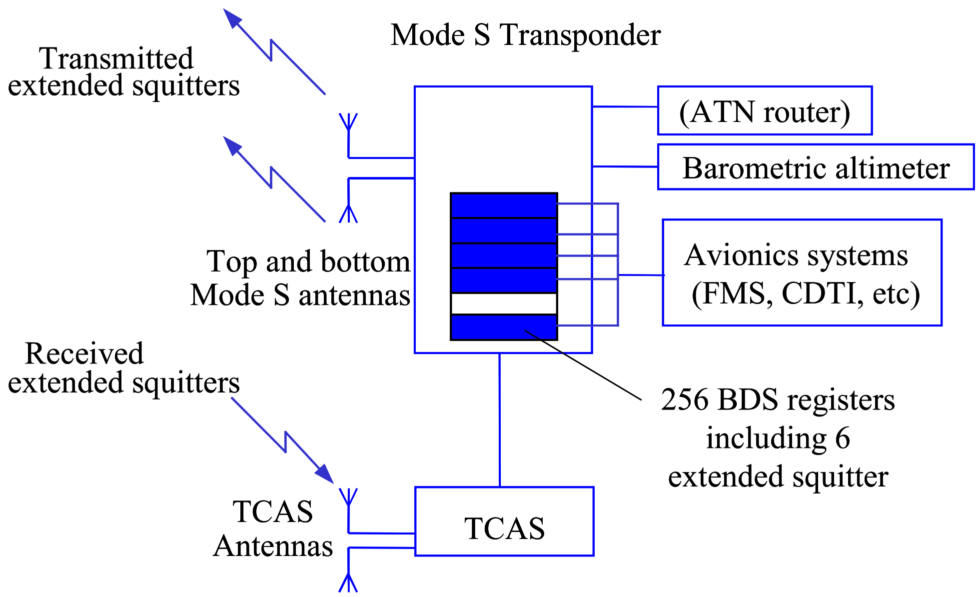


Figure G-1: 1090 ES Airborne Architecture

G.1.9 1090 ES messages are contained in Binary Data Store (BDS) registers. Six of the 256 BDS registers in the Mode S transponder contain extended squitters. These registers are frequently updated by the avionics systems.

G.1.10 The extended squitter registers are transmitted at frequent intervals autonomously by the transponder and can also be extracted by a request from a ground interrogator. If an extended squitter BDS register is not updated for 2 seconds, then it is cleared by the transponder, thus preventing the transponder transmitting out-of-date information.

Ground terminal design

G.1.11 A diagram of an extended squitter ground station is shown below.

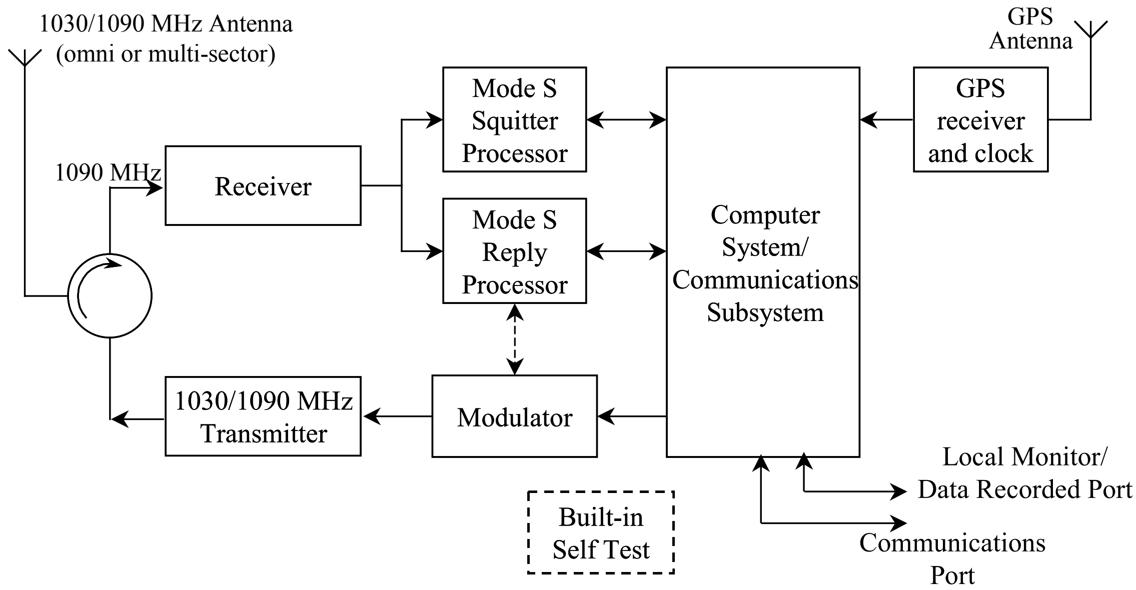


Figure G-2: 1090 ES Ground Architecture

G.1.12 For surveillance of aircraft on the airport surface, an ADS-B receiving station will include a number of simple receivers. Because of the multipath environment at most airports, and obstruction by buildings, a single receiving antenna would not be sufficient to cover the full airport. It has been shown through testing at Logan Airport that approximately four receiving antennae would be appropriate for an airport of that size.

Standards

G.1.13 The SARPs for the Extended Squitter have been agreed by ICAO SICASP (Secondary Surveillance Radar Improvement and Collision Avoidance Systems Panel) and are included in the latest issue of ICAO Annex 10.

G.1.14 ICAO SICASP has also published the Manual of Mode S Specific Services, Doc 9688 in 1997. EUROCAE has developed MOPS for a Mark 4 Mode S transponder. The characteristic defines the installation and inputs required to supply the aircraft data for use by the transponder and includes the Extended Squitter functionality. This document has also been published.

G.1.15 RTCA has developed “1090 MHz MOPS” which also define the message formats and protocols for Mode S Extended Squitter. This was published in January 2001.

G.1.16 The AEEC (Airlines Electronic Engineering Committee) has developed an ARINC characteristic (ARINC 718) that defines the “form and fit” (ie the physical interconnections, plugs, pin layouts, etc) of the required Mode S transponder avionics. This does not yet include the required functionality for the extended squitter.

G.1.17 There is some overlap between several of the above standards. The most recent standard and the main reference are the RTCA 1090 MHz MOPS (RTCA DO-260). It is intended that other standards will be adjusted to reflect this one.

G.1.18 All the relevant standards exist. A final effort is required to ensure the consistency of the documents.

Simulation Results

G.1.19 Numerous simulations have been conducted by the FAA and UK Civil Aviation Authority to ensure that 1090 ES does not have an adverse effect on the TCAS and SSR. These simulations show that 1090 ES can operate along side these other systems.

G.1.20 In terms of ADS-B performance, the most influential simulations were conducted by TLAT. These simulations used both VOLPE and SIEM models.

G.1.21 The results tend to indicate that:

- 1090 ES has a limited capacity to support FIS-B
- 1090 ES does not support long range applications (> 90 nm)
- 1090 ES will support short range applications (<20 nm)
- 1090 ES support for medium range applications (20 – 60 nm) is debated. Current best estimates from simulations conducted by Eurocontrol suggest that 1090ES can support ranges of up to 40 nm up to 2010.

Demonstrations

G.1.22 Mode S Extended Squitter has been demonstrated by several organisations, including Eurocontrol and the Cargo Airline Association in the US. Some early trials showed poor performance in the range of the extended squitters, although more recent trials have reported much better success. A further operational trial is currently being conducted by Honeywell for Airservices Australia

Pegasus (1090 MHz Frankfurt trial)

G.1.23 ADS-B flight trials using Mode S Extended Squitter in German airspace were performed in May 2000 by DFS Deutsche Flugsicherung, FAA and Eurocontrol, in collaboration with several industry organizations. Measurements of interference environments and reception performance were made in a variety of conditions. Airborne and ground-based receptions were analysed, and several receiving systems were evaluated.

G.1.24 **Air-to-Air Performance:** In the Frankfurt environment the measurements are consistent with the state vector and intent requirements and 40 nmi range requirements for the separation assurance application. At ranges beyond 40 nmi, as required to support a long range deconfliction application, the measured update rates would typically support the MASPS application requirements (state vector and intent information) up to a range of 75 nmi, and state vector information alone to 90 nmi, in most cases.

G.1.25 Concerning the Eurocontrol proposed criteria for autonomous operations to 150 nmi range, which include the reception of four TCPs, reception probability was observed to be generally adequate for ranges up to 70 nmi.

G.1.26 Performance measurements with the TCAS based receiver were generally similar to that measured with the LDPUs. However, the ranges were consistently shorter due to the less sensitive receiver and time sharing with TCAS surveillance functions.

G.1.27 There were certain exceptions to the effective air-to-air reception range observed offering both shorter and longer range performance. The worst case performance observed during the evaluation was an effective air-to-air range on the order of 40 nmi. However, it was subsequently demonstrated that by applying the advanced reception techniques (as defined in the 1090 MHz ADS-B MOPS) the effective reception range in this worst case situation would have been extended to approximately 60 nmi.

G.1.28 **Air-to-Ground Performance:** Three different receivers were evaluated at two sites. Differences were observed in the performance of the LDPU, ANS-MAGS and ERA receivers, with the LDPU the most capable and the ERA receiver the least. This is believed to be due the fact that the LDPU was the only receiver that implemented error correction. All three receivers demonstrated performance adequate for terminal operations; the differences were most apparent in long range, en route scenarios.

G.1.29 Air-to-ground reception capabilities were generally line-of-sight limited. An air-to-ground reception range in the Frankfurt environment of at least 150 nmi appears feasible with a single sensor using a properly sited, sectorized antenna.

G.1.30 Based on measurements from the ground station at Wiesbaden, air-to-ground reception performance for aircraft on final approach to land at Wiesbaden indicate that 1090 MHz ADS-B is capable of satisfying the requirements for a PRM application.

Operational Use

G.1.31 Although many large aircraft are equipped with a minimum Mode S capability, this does not include the Extended Squitter function. A very small number of commercial aircraft have already been upgraded to transmit extended squitter. British Airways have six such aircraft.

G.2 References

G.2.1 The following are the key references defining 1090 ES:

- Mode S SARPS, Annex 10, July 1998 [144].
- ED-73A: Minimum Operational Performance Specification for Secondary Surveillance Radar Mode S Transponders, May 1995 [86].
- ARINC 718A, Mark 4 Air Traffic Control Transponder (ATCRBS/Mode S), February 2002 [87]
- DO-260, Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B), RTCA SC-186, September 2000 (Also published by EUROCAE as ED-102) [28].
- DO181C, Minimum Operational Performance Standards for ATCRBS/Mode S Airborne Equipment, RTCA, July 2001 [131].
- Technical Link Assessment Report, Eurocontrol, March 2001 [15].

- Summary of the Functional and Technical Assessment of the ADS-B Link Architecture Alternatives, Interim Report, FAA, November 2001 [151].
- An analysis of the costs and benefits of ADS based on operational case studies - Results of Stage 1 ADS Programme CBA, Edition 0.4, Eurocontrol, September 2001 [38].
- OpEval Final Report, OpEval Coordination Group (OCG), April 2000 [145].
- OpEval-2 Final Report, OpEval Coordination Group (OCG), August 2001 [146].
- Runway Incursion Prevention System: ADS-B and D-GPS Data Link Analysis at Dallas-Fort Worth International Airport, NASA/CR-2001-211242, November 2001 [248]

G.3 Technical Assessment

G.3.1 General Description

Parameter	Value	Notes
Service topology	Air-ground datalink, Air-air broadcast, Uplink broadcast, Downlink broadcast	1090 MHz Extended Squitter includes a 'crosslink' for TCAS, which is a simple data link
ATN compliance	No	
Frequency band	1090 MHz	Complementary uplink broadcast service could be provided at 1030 MHz.
RF Channels	Single.	One channel at 1090 MHz provides air-air, air-ground and ground-air broadcast services.
Modulation scheme	PPM	Pulse Position Modulation
Bit rate	1 Megabit/sec	
Channel access method	Random	
Frequency availability (allocation status)	Frequencies already allocated and available.	Mode S operates on 1030 MHz and 1090 MHz. International spectrum allocation of the required 3 MHz channel exists. No further actions are required to secure suitable frequencies.
Dependencies	No	Not dependant upon the deployment of other technologies. May impact on other systems operating at the same frequency – TCAS and SSR (Mode A/C and Mode S)

G.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	No	
Message length	112 bits	Only 56 bits are available for ADS-B payload, the remaining 56 bits are used for identity and parity.
Transmission delay	-	RF propagation only.
Availability	-	Depends upon airborne architecture.
Integrity	10^{-6}	The probability of undetected message error is controlled by the parity field included in each squitter. 1 error in 10^{7} messages.
Continuity of function	-	Depends upon airborne architecture.
Capacity	Limited	Supports TLAT requirements for Core Europe in 2010, but beyond this date the level of 1090 Interference (FRUIT) reduces the system range below 40nm.
Coverage (airspace category) & Range	Range up to 120 NM However 40nm is more realistic in densely populated airspace	Coverage very dependent on traffic density and local deployment of other systems operating at the same frequencies. May be used in all airspace types. For air-ground surveillance it is not suitable for oceanic and remote areas. 120 NM range is not unrealistic in low to medium density scenarios.
Priority management	None	

G.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Completed	A large number of simulations have been conducted which demonstrate that 1090 ES could be deployed without adversely effecting TCAS and SSR operation. However, further simulations will be required to consider operation of ADS-B in an enhanced surveillance environment.
R&D Trials	Completed	Numerous R&D trials have been conducted by NATS (at QinetiQ Malvern, and Gatwick), STNA and Eurocontrol.

Pre-Operational Trials	Completed	Major flight trials have been conducted in: Germany (Pegasus trial): ADS-B flight trials using Mode S Extended Squitter in German airspace were performed in May 2000 by DFS Deutsche Flugsicherung, FAA and Eurocontrol, in collaboration with several industry organizations. Measurements of interference environments and reception performance were made in a variety of conditions. Airborne and ground-based receptions were analysed, and several receiving systems were evaluated. US (Operational evaluations in Ohio Valley and CAPSTONE)
Operational Trials	Partially completed	Airservices Australia has recently commenced an operational trial of 1090 ES to support ground surveillance.
Standards Development		
ICAO	Published	ICAO Mode S SARPs - Published, but may need updating to reflect recent MOPS changes. ICAO Manual of Mode S Specific Services
EUROCAE/RTCA	MOPS published	MOPS for 1090 MHz ADS-B (RTCA DO-260, EUROCAE ED-102) - Originally published in November 2000. Update published June 2002. MOPS for SSR Mode S Transponders (EUROCAE ED-73A)
AEEC	Published	ARINC 718, 718A Mark 4 Air Traffic Control Transponder (ATCRBS/MODE S)
ETSI	No activity	No activity is required
Other Standards	None	No activity envisaged
Conclusion	Nearly Complete	Standards work complete by 2002, with exception of possible SARPs updates.
Equipment Development		
Prototype airborne equipment status	Available	

Red-label (operationally capable) airborne equipment status	Available	Although many large aircraft are equipped with a minimum Mode S capability, this does not include the Extended Squitter function. A very small number of commercial aircraft have already been upgraded to transmit extended squitter. British Airways have six such aircraft. Honeywell has Mode S equipment for AT aircraft with the Extended Squitter function in production. Rockwell Collins 1090 ES equipment is close to production. In response to the Mode S Elementary Surveillance mandate, and the expected Enhanced Surveillance mandate, Airbus and Boeing are certifying Mode S transponders with Elementary Surveillance, Enhanced Surveillance, and 1090 Extended Squitter ADS-B Out functions, along with the requisite aircraft installation wiring. Initial deliveries and service bulletins for in-service aircraft will start in the first quarter of 2003, in support of fleet wide compliance by 2005.
Certification	No known issues	Certifiable equipment exists which is very close to the anticipated final requirements for 1090 ES
Conclusion	No remaining issues	
Prototype ground equipment status	Available	
Operationally capable ground equipment status	Available	1090 ES ground stations are manufactured by Sensis Corporation – available for both receive only and receive/transmit. They will be used in the Airservices Australia ADS-B trial which started in 2002.
Certification	No issues expected	
Conclusion	No issues expected	No issues are expected as 1090 ES ground stations are available for trials and relatively simple. Antenna design to ensure range is achieved is the only known issue and is not considered a problem.
System Deployment		
Ground deployment plans status	None known	No firm plans by ANSPs have been reported.
Aircraft fleet equipment plans status	Limited	Airbus have plans to make ADS-B-out via 1090 ES standard equipment from 2003. No known plans by airlines for retrofit.
Mandatory Carriage Status	None	No mandate has been promulgated
Conclusion	Limited	Despite significant recent decisions to support 1090 ES, no firms plans for it's deployment are currently available.

G.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Need to consider impact on TCAS and SSR (Mode A/C and Mode S)
Ground architecture	Multiple receiving antennae required at airports (e.g. 4 required at Logan Airport) [248] indicates that ground performance (squitter reception) is 30% less than airborne performance.

G.4 Cost Assessment

G.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of 1090 ES ground station	75,000	[231]
Installation	15,000	20% equipment cost
Total initial cost per ground station (1 transceiver)	**90,000**	
Yearly maintenance costs per ground station (1 transceiver)	7,500	10% initial hardware cost
Number of ground stations required	150	
Total ground station costs (1 transceiver)	**13,500,000**	

G.4.2 Airborne Costs

G.4.2.1 Costs assuming transceiver and RCP require upgrade

G.4.2.1.1 This case will apply to a percentage, say x%, of the aircraft.

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of Mode S Extended Squitter transceiver	40,600	Cost from [218]
Radio control panel (x 2)	16,400	Cost from [218]
GPS antenna	1,500	[38]
CDTI (x 2)	68,000	[38]
Upgrade of FMS	68,000	[38]
Integration, installation & certification		
Installation kit(s)	9,725	5% equipment cost
Service bulletin	19,450	10% equipment cost

Man-hours (80 euro/hour)	9,725	5% equipment cost
Operations & maintenance training		
Crew (6 crew) simulator training	77,000	[38]
Crew (6 crew) theoretical training	4,000	[38]
Simulator modification	8,000	[38]
Total initial costs per aircraft (1 transceiver)	**322,400**	
Yearly maintenance costs per aircraft (1 transceiver)	19,450	10% initial hardware cost

G.4.2.2 Costs assuming transceiver and RCP already installed

G.4.2.2.1 This case will apply to the remaining, (1-x)%, of the aircraft.

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of Mode S Extended Squitter transceiver	0	already installed
Radio control panel (x 2)	0	already installed
GPS antenna	1,500	[38]
CDTI (x 2)	68,000	[38]
Upgrade of FMS	68,000	[38]
Integration, installation & certification		
Installation kit(s)	2,500	Airbus figure
Service bulletin	0	Airbus figure: included in cost of installation kit
Man-hours (80 euro/hour)	2,400	Airbus figure
Operations & maintenance training		
Crew (6 crew) simulator training	77,000	[38]
Crew (6 crew) theoretical training	4,000	[38]
Simulator modification	8,000	[38]
Total initial costs per aircraft (1 transceiver)	**231,400**	
Yearly maintenance costs per aircraft (1 transceiver)	13,750	10% initial hardware cost

G.5 Industrial Assessment

G.5.1 Stakeholder Support

Stakeholder	Comments
FAA	FAA have selected 1090 ES as the initial ADS-B media
Eurocontrol	Eurocontrol have provisionally selected 1090 ES as the initial ADS-B media but work is ongoing to ascertain requirements post 2010.
IATA/AEA	JAFTI have recommended 1090 ES as the initial ADS-B media.
CANSO	CANSO have recommended that ANS providers having a requirement for broadcast datalink adopt, as a minimum, Mode S Extended Squitter for use during the period 2003-2012 [262]

G.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have 1090 ES transceiver equipment in production for AT aircraft. They additionally sell a transponder for the GA market. There is an expectation that when required to equip for Elementary Surveillance, airlines will equip with a box that achieves Elementary, Enhanced, and Extended Squitter, but that so far the orders for such units have not yet taken off. Currently a wider market is seen for 1090 ES compared to UAT.
Rockwell Collins	Rockwell Collins have Mode S equipment with 1090 Extended Squitter capability that is close to production. The 1090 Extended Squitter function is under development within Rockwell Collins. Prototype equipment exists and various trial projects have been conducted. The black label transponders with Extended Squitter capability concurrent with the introduction of Elementary and Enhanced surveillance are scheduled to be available after airframe certifications by mid-2003.
Sensis Corporation	Sensis Corporation manufacture 1090 ES ground stations, available for receive only, or receive/transmit. Their ground stations will be used for the ADS-B Airservices Australia trial which commenced in 2002.
UPS Aviation Technologies	UPS Aviation Technologies sell airborne transceivers capable of 1090 ES, or 1090 ES and UAT combined in the same unit.
Other	Other manufacturers include: Harris Information Systems and Thales Avionics.

G.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	Airbus will support 1090 ES (out) from 2003 and 1090 ES (in) from 2006/7. The architecture re-uses the TCAS receiver.
Boeing	Mode S equipment that has the Enhanced Surveillance and 1090 Extended Squitter capability, is being produced for Boeing airplanes according to the ARINC 718 standard, but the use of the equipment for Enhanced Surveillance or 1090 Extended Squitter is not yet airframe certified.

G.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Very mature system for ADS-B(out) but there is little experience of ADS-B (in)
Summary of Weak Characteristics	Lack of capacity and range. In particular simulations show that 1090 ES will not support spacing range requirements (40nm) after 2010. Re-use of SSR/TCAS frequency, in particular a safety case for re-use of TCAS receiver is required.
Conclusion: feasibility, maturity & timescale	1090 ES has reached full maturity. Operational deployment could begin within 12 months and be widespread by 2006.

H Mode S Enhanced Surveillance

H.1 Introduction

H.1.1 SSR Mode S is the intended replacement for the existing Monopluse SSR Mode A/C and may be used to support:

- **Mode S Elementary Surveillance**: Which is being implemented in the airspace of Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland, and requires airborne equipage of Mode S capable transponders from March 2003 up to 31 March 2005.
- **Mode S Enhanced Surveillance**; France, Germany and UK have published an AIC.
- **Mode S SVCs**: Which were ruled out from European ATN deployment plans after the ST15 study results; moreover, they would require a significant upgrade of Mode S transponders. Mode S SVCs are not considered.

H.1.2 Mode S Elementary Surveillance enables the use of the unique 24 bit aircraft address for selective interrogation and allows the Aircraft Identity to be acquired from the aircraft. It also enables to read out the flight level in 25 foot vertical resolution. Mode S Elementary Surveillance therefore constitutes a significant improvement of the Air Traffic Surveillance system in dense traffic areas.

H.1.3 Mode S Enhanced Surveillance consists of Elementary Surveillance supplemented by the extraction of airborne parameters known as Downlink Airborne Parameters (DAPs) to be used in the ground Air Traffic Management systems. Some parameters are for display to controllers, known as Controller Access Parameters (CAPs), and some are for (ATM) system function enhancements, known as System Access Parameters (SAPs).

H.1.4 Mode S Elementary/Enhanced surveillance makes use of the GICB service to extract aircraft data. GICB is one of three “Mode S Specific Services” which have been standardised by ICAO, the others are:

- Uplink and downlink broadcasts
- MSP (Mode S Specific Protocol): two-way connectionless link (datagram), with no flow control, no guarantee of ordered delivery, no message loss detection/correction

H.1.5 Options for the implementation of Mode S Enhanced Surveillance may involve the use of MSP so as to optimise aircraft data collection based on events (a change in parameter value or according to thresholds, for slowly varying parameters), instead of having data transmitted on a periodic basis. This is known as “Dataflash”, and described in the Mode S “MSP” section below.

H.1.6 Mode S Squitter and Extended Squitter (1090 ES), in support of ACAS and ADS-B/TIS-B, only involve the transponders (and potentially a dedicated ground network of ADS-B/TIS-B stations). Thus, these technologies are not considered as linked to “pure” Mode S datalink. Mode S 1090 ES is described in Annex G.

H.1.7 It is assumed here that the initial deployment of Mode S ground stations will make use of rotating antenna technology.

H.2 References

- Mode S Charter, Version 1.1 Eurocontrol, December 2000 [21].
- Concept of Operations Mode S in Europe (Mode S CONOPS), SUR.ET2.ST02.1000-CNP-01-00 Eurocontrol, November 1996 [22].
- Specimen Eurocontrol Mode S Aeronautical Information Circular (AIC), Version 1.0 (available from www.eurocontrol.int/mode_s), Eurocontrol, July 2000 [24].
- ARINC 718-4 Mark 3 Air Traffic Control Transponder (ATCRBS/MODE S). This standard describes an Air Traffic Control Radar Beacon System/Mode Select (ATCRBS) airborne transponder, December 1989 [87].
- 718A Mark 4 Air Traffic Control Transponder (ATCRBS/MODE S) [88].
- Mode S Elementary Surveillance Transition Plan [117].
- DO181C, Minimum Operational Performance Standards for ATCRBS/Mode S Airborne Equipment, July 2001 [136].
- “The Concept of Operations - Mode S in Europe”, document SUR.ET2.ST02.1000-CNP-01-00, Edition 2, Nov 1996 [168].
- JAA Administrative & Guidance Material LEAFLET NO 13: Certification of Mode S Transponder Systems for Elementary Surveillance [188].
- ICAO Manual on Mode S Specific Services, Doc 9688, First Edition, 1997 (An update to this document is expected in 2001) [81].
- EUROCAE MOPS for Secondary Surveillance Radar Mode S Transponders, ED-73A, February 1999 [86].
- EUROCAE DO-218B MOPS for the Mode S Airborne Data Link Processor [82].
- ED-101: "Minimum Operational Performance Specification for Mode S Specific Service Applications" September 2000 [83].
- ED-86: Equipment Characteristics for Mode S Transponders with Extended Interface Functions July 1997 [84].
- ED-82A: Minimum Operational Performance Specification for Mode S Aircraft Data Link Processors [85].

H.3 Technical Assessment

H.3.1 General Description

Parameter	Value	Notes
Service topology	Point-to-point	This is a Mode S Specific Service. Data collection is optimised thanks to an asynchronous mechanism: on the air side, data extracted from the avionics busses are periodically polled to refresh dedicated Mode S transponder's memory register. On the ground side, data extraction through the Mode S link is initiated when required according to ground users requests. Aircraft data allocation to the transponder's memory is pre-determined/standardised by ICAO doc 9688. The retained parameters for initial implementation of Mode S enhanced surveillance in Europe are the following: - For CAP D/L service: Magnetic Heading, IAS/Mach nr - For CAP & SAP: Selected Altitude - For SAP: Vertical Rate, Track Angle Rate, Roll Angle, Ground Speed, True Track Angle These data fit into 2 Mode S GICB registers (BDS 50/60). Wind vector, as required by ODIAC/CAP, would require a third register to be extracted (BDS 44) **For Mode S Specific Protocol (MSP):** Limited addressing at the application level with 63 channels available. Non-connected mode, no flow-control mechanism.
ATN compliance	No	
Frequency band	1030, 1090 MHz	
RF Channels	Two distinct channel	1030 MHz for uplink transponder interrogations 1090 MHz for downlink replies
Modulation scheme	DPSK and PPM	Uplink: Differential Phase Shift Keying (DPSK) Downlink: Pulse Position Modulation (PPM)
Bit rate	Uplink: 4 Mb/s Downlink: 1 Mb/s	Note: Data transfer is only available during the bean dwell, hence effective data rate for a 6 second rotation is approximately 600 bps.
Channel access method	Managed via Mode S interrogation scheduling	Access is managed according to air situation (in order to reduce interference/FRUIT) and user demand for GICB transactions.

Parameter	Value	Notes
Frequency availability (allocation status)	Frequencies available.	Global allocation of 1090/1030 MHz to SSR and Mode S systems 1030/1090 RF channels are also used by: classical SSR Surveillance, Mode S elementary surveillance, Mode S squitter & TCAS, Mode S extended squitter, and other Mode S data services described above. Mode S elementary surveillance is a pre-requisite for Mode S datalink; It can be anticipated that the available bandwidth in the antenna's beam for a given aircraft will be shared between Mode S Enhanced Surveillance and SVC/MSP. However, the impact of the deployment of Mode S Enhanced surveillance on critical systems/services like Mode S elementary surveillance, TCAS II and 1090ES/ADS-B/TIS-B/ASAS are to be assessed.
Dependencies	UTC synchronisation is required in ground stations to enable time stamping of collected aircraft data	Data in the Mode S transponder's registers does not include timestamps 1030/1090 RF channels are also used by: Mode S elementary surveillance, Mode S squitter & TCAS, Mode S extended squitter, and other Mode S data services described above. Mode S elementary surveillance is a pre-requisite for Mode S datalink; It can be anticipated that the available bandwidth in the antenna's beam for a given aircraft will be shared between Mode S Enhanced Surveillance and SVC/MSP. However, the impact of the deployment of Mode S Enhanced surveillance on critical systems/services like Mode S elementary surveillance, TCAS II and 1090ES/ADS-B/TIS-B/ASAS are to be assessed.

H.3.2 Performance Characteristics

H.3.2.1 Performance Characteristics for Mode S data link based on GICBs

Parameter	Value	Notes
Multiple QoS Profiles	No	
Message length	112 bits	56 bits user data the remainder is address and parity information.
Transmission delay	Periodic collection with rotating antenna: Mean value: (air_refresh_rate / 2) + ground_processing_delay	Measured from the availability of data in the avionics to its availability for the ground user at the Mode S data link processor interface. When using rotating antenna technology, Mode S Enhanced Surveillance is particularly suitable for periodic data collection The age of the data extracted is determined by the re-fresh rate of the BDS within the transponder, which is either 0.5 or 1 s intervals. When data is extracted on an event (eg having exceeded an alarm threshold) the notification may be delayed by upto the rotation period. However, this still inside the ODIAC 8 second requirement. It is expected that aircraft data associated with a strong operational requirement on the time-delay axis will have a high refresh rate in the transponder on the airborne side. Typical values: Air Refresh Rate: 500 ms to 5 sec depending on data (cf. ICAO Doc 9688) Ground Processing Delay: 500 ms
Availability	Airborne part: 99.9% (transponder & ADLP) Ground part: 99.99% (ground stations); 99.999% (fault tolerant GDLP)	Source: Eurocontrol ST15 study; figures are either estimates or objectives.
Integrity	Residual error: BER = 10^{-9} undetected errors, 10^{-7} detected errors	Accuracy, as observed by the user, depends on the avionics characteristics (sensors, pre-processing, resolution, update rate). BDS 50 & 60 are updated every 0.5 s in the transponder (Source: ICAO doc 9688).
Continuity of function	See availability	
Capacity	500 aircraft	See ST15 & MADAM results. 500 aircraft can be in coverage, with a rotating antenna (4 sec), 2 or 3 GICBs per aircraft per scan (without any other datalink transaction)

Coverage (airspace category) & Range	150 nm	Airspace category: all except surface operations For 1 station: range = ~150 NM , depending on antenna scan period. For a cluster of stations, accessible from 1 subnetwork point of attachment: range = 250 to 300 NM.
Priority management	No	

H.3.2.2 Performance Characteristics for Mode S Specific Protocol (MSP)

Parameter	Value	Notes
Multiple QoS Profiles	No	
Message length	Up to 151 bytes uplink, 159 bytes downlink of user data	
Transmission delay	Depends on rotation speed	Mean value: typical values In the same order as the antenna scan period (e.g. 5 seconds)
Availability	Airborne part: 99.9% (transponder & ADLP) Ground part: 99.99% (ground stations); 99.999% (fault tolerant GDLP)	
Integrity	Residual error: BER = 10^{-9} undetected errors, 10^{-7} detected errors	
Continuity of function	Design Issue	
Capacity	500 aircraft	500 aircraft in coverage, with a rotating antenna (4 sec), with 25% uplink traffic, throughput is about 150 bits/sec/aircraft (total traffic, including GICBs) (See ST15 & MADAM results.)
Coverage (airspace category) & Range	Same as above	
Priority management	No	

H.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Completed	MADAM Mode S Analysis & Modelling (study undertaken in 1990 by Eurocontrol and CENA in order to assess the throughput and delay of the Mode S subnetwork)
R&D Trials	Completed	Trials conducted by UK NATS and Eurocontrol
Pre-Operational Trials	Partially completed	Extensive trials have been conducted in Europe and the US in the 90's. Although they didn't have a pre-operational status, it is noticeable that commercial aircraft were equipped with dedicated Mode S ES equipment; this resulted in hundreds of commercial flights taking part in these trials. In Europe, trials were mainly performed by the UK, France and Germany using experimental Mode S ground infrastructures, and about 20 equipped aircraft, among which laboratory aircraft (e.g. QinetiQ's BAC 1-11) and a dozen commercial aircraft (1 F900 EX from Dassault Falcon Service, 2 Air France A310, 1 767 from Britannia, British Airways, etc.)
Operational Trials	Partially completed	French Mode S experiments include the processing of downlink data. Since the first A310 from Air France was equipped in may 1992, data from aircraft are being collected by the AGLAE system (Air Ground data Link Applications Experimentation). Currently 2 A310 from Air France, a Falcon from DFS, and a experimental aircraft from DRA are equipped.
Standards Development		
ICAO	Published	SARPS and ICAO Doc. 9688
EUROCAE/RTCA	Published	EUROCAE ED73A MOPS for Secondary Surveillance Radar Mode S Transponders - Issued in May 95, reviewed in Sept. 2002 for the integration of hijack-related modifications
AEEC	Published	ARINC 718A Mark 4 Air Traffic Control Transponder (ATCRBS/MODE S).
ETSI	No activity	
Other Standards	No activity	
Conclusion	Mature	

Equipment Development		
Prototype airborne equipment status	Available	Several manufacturers will propose something in Dec. 2002. Mode S transponders with sufficient data link capability at the link layer exist (corresponding to TCAS equipment). External prototype equipment (ADLP) for Enhanced Surveillance capability exists as well.
Red-label (operationally capable) airborne equipment status	Available	Special equipment for trial purposes (EEC is using such an equipment) In response to the Mode S Elementary Surveillance mandate, and the expected Enhanced Surveillance mandate, Airbus and Boeing are certifying Mode S transponders with Elementary Surveillance, Enhanced Surveillance, and 1090 Extended Squitter ADS-B Out functions, along with the requisite aircraft installation wiring. Initial deliveries and service bulletins for in-service aircraft will start in the first quarter of 2003, in support of fleet wide compliance by 2005.
Certification	No known issues	
Conclusion	Mature	
Prototype ground equipment status	Available	POEMS ground stations implemented on site POEMS - Pre-Operational Mode S Ground Stations (1997-2001)
Operationally capable ground equipment status	None	
Certification	No known issues	
Conclusion	Mature	
System Deployment		
Ground deployment plans status	Yes	See mandate
Aircraft fleet equipment plans status	Some	Some aircraft are already equipped with Mode S transponders capable of support elementary and enhanced surveillance
Mandatory Carriage Status	Yes	The UK, France, and Germany have indicated their intention to mandate Enhanced Surveillance by publishing an AIC. A mandatory carriage will exist for Mode S Elementary Surveillance in 6 European Core Area States (from March 2003 to 31st March 2005).
Conclusion	Being deployed	

H.3.4 Complexity Assessment

Parameter	Constraints
Airborne architecture	Requires upgrade of existing Mode S transponders.
Ground architecture	Requires ground data link processors attached to clusters of ground stations. Coverage redundancy enhances datalink performances, but is limited by number of available interrogator codes (II codes).

H.4 Cost Assessment

H.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of upgrade of existing Mode S Elementary Surveillance ground station equipment to Mode S Enhanced Surveillance	0	No upgrade of Mode S Elementary Surveillance sensors is required [237]
Installation	0	
Engineer maintenance training	0	
Project management (80 euro/hour)	0	
Total initial cost per ground station	**0**	
Yearly maintenance costs per ground station	0	
Network costs	**11,900,000**	Figure in [237] increased by 150/88 sensors to cover Europe
Centre costs	**76,700,000**	Figure in [237] increased by 150/88 sensors to cover Europe
Total ground system cost	**88,600,000**	

H.4.2 Airborne Costs

H.4.2.1 Costs assuming transceiver and RCP require upgrade

H.4.2.1.1 This case will apply to a percentage, say y%, of the aircraft.

Specific equipment and operations	**Value for AT digital (euro)**	**Notes**
Hardware		
Cost of transceiver capable of Enhanced Surveillance	40,600	Cost from [218]
Radio control panel (x 2)	16,400	Cost from [218]
Integration, installation & certification		
Installation kit(s)	2,850	5% equipment cost
Service bulletin	5,700	10% equipment cost
Man-hours (80 euro/hour)	2,850	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**68,400**	
Yearly maintenance costs per aircraft (1 transceiver)	5,700	10% initial hardware cost

H.4.2.2 Costs assuming transceiver and RCP already installed

H.4.2.2.1 This case will apply to the remaining (1-y)%, of the aircraft.

Specific equipment and operations	**Value for AT digital (euro)**	**Notes**
Hardware		
Cost of transceiver capable of Enhanced Surveillance	0	Cost from [218]
Radio control panel (x 2)	0	Cost from [218]
Integration, installation & certification		
Installation kit(s)	2,500	Airbus figure
Service bulletin	0	Airbus figure: included in cost of installation kit
Man-hours (80 euro/hour)	2,400	Airbus figure
Total initial costs per aircraft (1 transceiver)	**4,900**	
Yearly maintenance costs per aircraft (1 transceiver)	0	10% initial hardware cost

H.5 Industrial Assessment

H.5.1 Stakeholder Support

Stakeholder	Comments
Eurocontrol	Eurocontrol are supporting the introduction of the Elementary Surveillance mandate in 2003 and the development of POEMS ground stations.
UK, France and Germany	These countries are proposing a mandate for Enhanced Surveillance

H.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have Mode S equipment with Enhanced Surveillance capability in production. Honeywell will also produce equipment for the AT market with Elementary, Enhanced and 1090 ES in the same box. Other combinations of functionality are also likely to be available – what Honeywell produces depends what the airlines want.
Rockwell Collins	Rockwell Collins have Mode S equipment with Enhanced Surveillance capability that is close to production. Enhanced Surveillance is an evolution of Elementary Surveillance. The transponder combining these two functions is to be available coincident with the Extended Squitter capability, and concurrent with airframe certification schedules. The equipment is technically ready; but the roll-out is scheduled to happen per airframe certification scheduling.

H.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	Airbus intend to support Mode S Enhanced Surveillance by 2003.
Boeing	Mode S equipment that has the Enhanced Surveillance and 1090 Extended Squitter capability, is being produced for Boeing airplanes according to the ARINC 718 standard, but the use of the equipment for Enhanced Surveillance or 1090 Extended Squitter is not yet airframe certified.

H.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	At the ground sub-network interface, aircraft data is less than (500 ms + airborne refresh rate) old. Standards maturity achieved. Live trials have been successfully conducted. This is due to the asynchronous data refreshment/collection mechanism used. The Mode S specific Protocol (MSP)allows quick transmission of small amounts of data and optimisation of Enhanced Surveillance by implementing on-event data transmission.
Summary of Weak Characteristics	Current experimental platform is limited Update rate as seen from the ground users, is limited by the rotating antenna scan period (4 or 5 secs). Downlinked parameters are not time-stamped until extracted by the ground system. Level of stakeholders commitment. The Mode S specific Protocol (MSP) does not include flow control or guarantee of delivery
Conclusion: feasibility, maturity & timescale	Mode S Elementary Surveillance is subject to a mandate from 2003 to 31st March 2005 for 6 core European States. France, Germany and the UK are also intending to mandate Enhanced Surveillance.

I VDL Mode 3

I.1 Introduction

I.1.1 The VHF Digital Link Mode 3 (VDL3) system provides multiple channels to operate on one 25 kHz frequency assignment. The VDL3 system uses the same physical layer as VDL2 (D8PSK modulation) and employs a 4.8 kilobits per second vocoder for voice operation.

I.1.2 VDL3 has been selected by the FAA for the future provision of voice and data communications, and forms the basis of the FAA's Next Generation Air/Ground Communications (NEXCOM) programme.

I.1.3 Subject to meeting NARC criteria, the FAA will deploy VDL3 to support voice in the high-altitude en-route airspace by 2009 and data around 2012. The FAA do not propose to offer AOC services through their VDL3 network.

NEXCOM

I.1.4 The FAA has determined that at the current growth rate for air traffic it will run out of 25 kHz spaced voice communication frequency allocations by approximately 2009. The FAA's solution to this problem is NEXCOM, which utilizes VDL3.

I.1.5 The FAA Administrator convened the NEXCOM aviation Rulemaking Committee (NARC) to advise the agency on an approach to meeting the needs of future voice and data services. In 2001 the NARC issued a recommendation to expedite a voice and data demonstration of the VDL3 system.

I.1.6 NEXCOM currently plans to operate the system in a 2-Voice/2-Data configuration (see configuration options below), but intends to support other combinations where required. In the fully operational state, the NEXCOM system will accommodate both voice and data and will have the flexibility to determine how the channel resources are applied for voice and data.

System description

I.1.7 VDL3 employs Time Division Multiple Access (TDMA). The system divides a radio transmission into four 30-millisecond segments which equates to a 120-millisecond frame. Each of these segments can be assigned to different user groups to achieve a theoretical four-fold increase in effective use of a channel.

I.1.8 The system software digitises and compresses 120 ms of the sound into 576 bits that are transmitted in one burst during a 30-millisecond segment. By using the same software to decompress the burst on the receiving end, high quality reproduction of voice waveforms is achieved. Because the basic transmission of the radio is a digital signal, data can also be transmitted on one of the other time division slots.

I.1.9 As stated above, VDL3 is a time-slotted system. All participants in the system operate in an environment where time is distributed from the ground radios to the airborne radios using radio beacon signals. There is a hierarchy of time scales associated with VDL3. The important concepts include:

- **TDMA Frame**. The basic unit of time is a TDMA frame, which is 120 milliseconds (ms). In any voice communication, a radio will transmit digitised voice bits periodically once per frame.
- **Time Slot**. Frames are divided into time slots. There are two classes of VDL3 configurations which are based on two different time slot sizes. For the 4-slot configurations, the frames are divided into four 30 ms time slots. For the 3-slot configurations, the frames are divided into three 40 ms time slots.
- **Subslot**. For most configurations (except 3T) each time slot is divided into two subslots. The first subslot is devoted to Management (M) channel transmissions and the second subslot is devoted to voice or data (V/D) transmissions.
- **MAC Cycle**. A MAC cycle consists of two TDMA frames, an even frame followed by an odd frame. There is exactly one uplink M channel beacon per MAC cycle.
- **Epoch**. An epoch consists of 25 MAC cycles, or 6 seconds. The concept of an epoch is used to define how to synchronize a ground radio with an "absolute" time source which provides time update signals at a rate of one per second.

I.1.10 In certain circumstances it may be desirable that ground stations have their time coordinated. In that case they are synchronized to an absolute time source related to Universal Coordinated Time (UTC). At times, airborne radios may lose ground/air time coordination. When this happens, special procedures must be followed.

Configurations

I.1.11 The VDL3 system provides for a variety of different system configurations. The various configurations differ in the way that the different time slot resources are allocated to different user groups. A user group consists of a ground radio and a number of airborne radios which are all interconnected by voice and/or data communications.

I.1.12 At any given time different user groups can be in different configurations. An airborne radio does not need to know configuration information prior to net initialisation. This information is provided by the ground station.

I.1.13 There are 4-slot configurations and 3-slot configurations. The 4-slot configurations provide guard time sufficient to allow interference-free communication up to a range of 200 nautical miles (nmi). For long range scenarios, the 3-slot configurations provide for 600 nmi.

I.1.14 The 4-slot configurations include the following:

- **4V**. Provides 4 voice channels (no data) in one 25 kilohertz (kHz) channel. This mode may, as an option, include downlink M channel transmissions and features such as urgent/priority access, semiautomatic frequency change, and caller ID.
- **2V2D**. Provides 2 voice and 2 data channels in one 25 kHz channel. These are paired so that one user group uses one voice and data time slot pair and a second, independent, group uses the other voice and data pair.

- **3V1D**. Provides 3 voice channels and 1 data channel in one 25 kHz channel. The three voice channels are completely independent; however, the single data channel is shared by the three user groups.
- **3T**. Provides a trunked capability shared by all users in one 25 kHz channel in which 1 out of 4 time slots is available for voice or data and 2 out of 4 time slots are available exclusively for data. The fourth time slot is used exclusively for channel management functions.

I.1.15 The 3-slot configurations include the following:

- **3V**. Provides 3 voice channels (no data) in one 25 kHz channel. This mode is analogous to 4V, but provides more propagation guard time.
- **2V1D**. Provides 2 voice and 1 data channel in one 25 kHz channel. This mode is analogous to 3V1D, but provides more propagation guard time.
- **3S**. Provides a single voice channel in one 25 kHz channel. The same digital voice bit-stream can be transported on each of 3 time slots used by 3 separate ground sites to provide coverage over an area larger than that which could be provided by a single ground site.
- **2V1X**. Provides 1 wide area voice channel for 2 separate ground stations and reserves another independent channel in one 25 kHz channel. The independent channel is defined separately in its own beacon.

I.1.16 Whether a slot is used for voice or data is indicated by V or D in each slot. The direction of the arrow indicates whether the M channel in a slot is used for uplinks or downlinks.

Airborne terminal design

I.1.17 The NEXCOM architecture includes:

- A Multi-Mode VHF radio, supporting 25 kHz voice, VDL3, 8.33 kHz voice (optional), and VDL2 (optional)
- A Radio Control Panel (RCP)
- A Communications Management Unit (CMU) (optional)

Ground terminal design

I.1.18 A simplified diagram of the ground infrastructure intended for the NEXCOM programme is illustrated below.

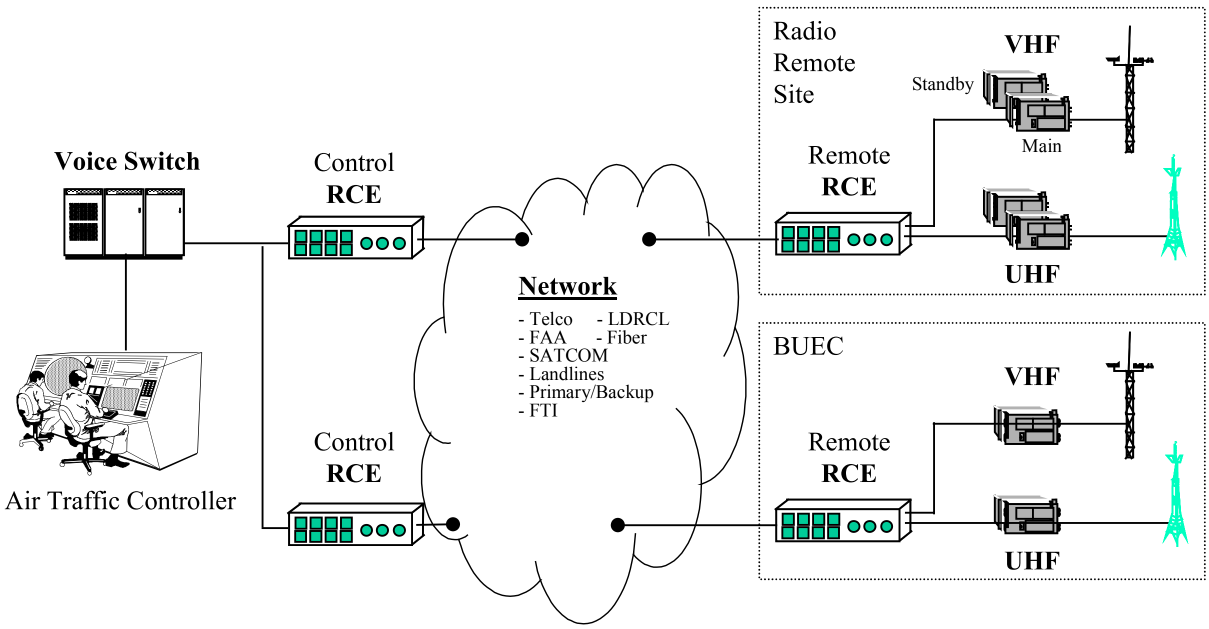


Figure I-1: NEXCOM ground architecture

Standardisation

I.1.19 The ICAO standards for VDL3 are complete. RTCA has developed MASPS and MOPS for the system. No activity is underway in EUROCAE, ETSI, or AEEC.

Demonstration

I.1.20 FAA has scheduled a series of three tests of VDL3, beginning October 2002 and ending October 2004. These will demonstrate the quality of voice communications and the integration of voice and data. The trials will also demonstrate that the ground radios can work with new digital aircraft equipment and other ATC equipment, and validate that VDL-3 can be certified as safe for aircraft operations.

I.1.21 System demonstration I will demonstrate technical feasibility of the VDL3 system and will take place in October 2002. MITRE avionics, on William J. Hughes Technical Center (WJHTC) aircraft, and ground system prototype equipment will be used.

I.1.22 During the demonstration, scenarios will feature the transit of aircraft, one Boeing 727 and one Convair 580, through two airspace sectors. These activities will demonstrate technical aspects of NEXCOM including:

- Voice Quality
- Integrated Voice and Data
- Stuck Microphone Resolution
- Next channel Uplink
- Urgent Down Link Request
- Antiblocking

Operation

I.1.23 The FAA have significant deployment plans for VDL3 provided the results of operational trials are successful.

I.2 References

I.2.1 The following key references define VDL3:

- Standards and Recommended Practices (SARPs) for VHF Digital Link, Annex 10, Volume III, Part I, ICAO [33].
- Technical Manual – AMCP/7-WP81 Appendix B to the report on Agenda Item 1 [189].
- Implementation Manual – AMCP/7-WP81 Appendix C to the report on Agenda Item 1 [190].
- DO-271, Minimum Operational Performance Standards (MOPS) for Aircraft VDL Mode 3 Transceiver Operating in the Frequency range 117.975-137.000 MHz, RTCA [73].
- DO-224A, Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques, RTCA [75].
- GAO-02-710 National Airspace System, FAA's approach to its New Communication system appears prudent, but challenges remain, FAA, July 2002 [196].
- NEXCOM System Requirements Document, FAA-E-2958, FAA, January 2002 [202].
- NEXCOM Multimode Digital Radio, FAA-E-2938, FAA, July 2001 [203]
- NEXCOM Next Generation Air/Ground Communications, Jim Eck, FAA, October 2001 [204].
- NEXCOM Avionics Approach, Sandra Anderson, FAA, October 2001 [205].
- Why VDL-3? The rationale behind the FAA's technology choice for NEXCOM, FAA, September 2001 [206].
- DO-279, Next Generation Air/Ground Communications (NEXCOM) Principles of operation for VDL Mode 3, RTCA [259]

I.3 Technical Assessment

I.3.1 General Description

Parameter	Value	Notes
Service topology	Point-to-Point	Broadcast uplinks can also be supported Uplink and Downlink broadcast are the primary mode of operation for voice communications.
ATN compliance	Yes	Additional voice services also included.
Frequency band	118 – 136.975 MHz	Provides up to four voice/data circuits on a single 25 KHz channel assignment.
RF Channels	Single 25 KHz channel	
Modulation scheme	D8PSK	
Bit rate	31.5 kbps	ST15 [2] estimates the effective data rate as 5040 bps.
Channel access method	TDMA	Limited to 4 slots Typical Configurations 4 Slot: 4V (4 voice) 3V1D (3 voice / 1 data) 2V2D (2 voice / 2 data) 3T (trunked voice and data) 3 Slot (extended range): 3V (3 voice) 2V1D (2 voice / 1 data)
Frequency availability (allocation status)	No operational frequencies currently assigned in Europe or North America	
Dependencies		Synchronised time source needed to maintain TDMA timing for multiple ground stations operating simultaneously on the same frequency in a given area.

I.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Yes, VDL3 supports up to 4 levels of priority for data messaging.	Manual on VDL Technical Specifications – Table 5-57 VDL3/ ATN Priority Mapping
Message length	TDMA with 30 ms/slot, 4 slots/frame	
Transmission delay	2V2D Uplink (95%): 0.7s Downlink (95%): 4.6s	Simulation based on 34 data link equipped aircraft per sector with Load Factor of 1. High priority message transmission delay Recent MITRE OPNET simulation results
Availability	Designed in U.S. to meet .99999 for voice service Data service availability requirement .999	Data service availability higher if established as a critical service
Integrity	10^{-6}	Required for data communications in the U.S. (CPDLC Build 1 and 1A)
Continuity of function	Service restoration times and continuity of function are a function of the overall system architecture.	Link monitoring capabilities of the VDL 3 enable earlier detection of the failed condition.
Capacity	4.1 kbps for 3V 1D 8.2 kbps for 2V 2D 12.4 kbps for 3T	Data throughput for a single sector (does not take voice capacity into account)
Coverage (airspace category) & Range	200 NM range Up to 600 NM range or radio horizon (whichever is smaller)	Applies to 4 slot configurations Applies to 3 slot configurations
Priority management	Supports up to 4 levels of priority	Messages with higher priority received by the media access control are allocated available data slots ahead of message with lower priority. Otherwise, messages with the same priority are served based on their time of arrival.

I.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Completed	Years of modelling and simulation
R&D Trials	Completed	Prototypes built by US and UK. Interoperability testing between US and UK in 1999. Flight tested.
Pre-Operational Trials	Partially completed	FAA has scheduled a series of three tests of VDL3, beginning October 2002 and ending October 2004: Demonstration of the quality of voice communications and the integration of voice and data. Demonstration that the ground radios can work with new digital aircraft equipment and other ATC equipment. Validation that VDL-3 can be certified as safe for aircraft operations.
Operational Trials	Planned	See FAA NEXCOM programme
Standards Development		
ICAO	Published	SARPS, Technical Manual and Implementation Manual are all complete.
EUROCAE/RTCA	RTCA MASPS and MOPS published No EUROCAE activity planned	DO-271, Minimum Operational Performance Standards (MOPS) for Aircraft VDL3 Transceiver Operating in the Frequency range 117.975-137.000 MHz, RTCA [73]. DO-224A, Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques, RTCA [75].
AEEC	ARINC 750 X	Draft AEEC characteristic has been developed built upon the ARINC 750 VDR characteristic, expected to be adopted.
ETSI	No activity planned	
Other Standards	None	
Conclusion	Technical specifications completed for Digital Voice and Data	
Equipment Development		
Prototype airborne equipment status	Available	Prototype airborne radios exist

Red-label (operationally capable) airborne equipment status		Under development by Rockwell/Collins, Honeywell, and Avidyne
Certification	Certification of the vocoder	No aviation experience with certification of vocoders.
Conclusion	Prototype airborne equipment available	
Prototype ground equipment status	Available	Prototype ground equipment exists
Operationally capable ground equipment status	Available	FAA has in 2002 issued contracts for operational equipment
Certification	No known issues	
Conclusion	Prototype ground equipment available	
System Deployment		
Ground deployment plans status	None in Europe	Multi Mode Digital Radios capable of VDL-3 deployed in US ground infrastructure beginning 2002. Plan to begin activate VDL 3 for air/ground comm in high altitude enroute airspace in 2009/2010.
Aircraft fleet equipment plans status	None in Europe	
Mandatory Carriage Status	None in Europe	European carriers who fly into US airspace will need to be equipped in 2009/2010
Conclusion	No European Deployment Currently Foreseen	

I.3.4 Complexity Assessment

Parameter	Constraints
Airborne architecture	No known issues
Ground architecture	Only needed to maintain TDMA timing for multiple ground stations operating simultaneously on the same frequency in a given area.

I.4 Cost Assessment

I.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of VDL3 ground station	150,000	[228]
Installation	30,000	20% equipment cost
Total initial cost per ground station (1 transceiver)	**180,000**	
Yearly maintenance costs per ground station (1 transceiver)	15,000	10% initial hardware cost
Number of ground stations required	150	
Total ground station cost (2 transceiver)	**27,000,000**	

I.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of VDL3 airborne transceiver	56,500	Estimate based on [38]
Antenna (x 2)	2,000	Estimate based on [38]
Upgrade of Radio Control Panel (RCP) x 2	19,000	[216]
Upgrade of Communications Management Unit (CMU)	8,000	[216]
Upgrade of Data Link Control Display Unit (DCDU)	6,000	[216]
Integration, installation & certification		
Installation kit(s)	4,275	5% equipment cost
Service bulletin	8,550	10% equipment cost
Man-hours (80 euro/hour)	4,575	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**108,900**	
Yearly maintenance costs per aircraft (1 transceiver)	9,150	10% initial hardware cost

I.5 Industrial Assessment

I.5.1 Stakeholder Support

Stakeholder	Comments
FAA	VDL3 is the currently selected system to provide for the FAA's future aeronautical voice and data communications needs, as part of the US FAA's NEXCOM program.
Eurocontrol	No activity
ARINC	No known plans
SITA	No known pans

I.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have airborne equipment under development to in support of the FAA Demonstration/Validation plan. This is an FAA-funded activity. They expect to have red-label equipment ready by the end of 2004. Honeywell are helping the FAA to develop their transition plans. They are also actively involved in RTCA standards development under SC-198. There are potential obstacles, in terms of frequency planning, to be overcome in Europe. The initial integration of digital VDL3 radios with analogue voice radios, which for a time must co-exist, potentially poses technical problems which will have to be overcome.
Rockwell Collins	VDL3 equipment is under development within Rockwell Collins. Rockwell Collins is under contract with the FAA for production of prototype development. The current schedule calls for red label equipment by Jun 2003 and black label equipment by June 2004.

I.5.3 Airframer/Integrator Perspective

Airframer	Comments
Boeing	Boeing are monitoring progress on VDL3, but do not currently have significant activity in the area. They see the standards for VDL3 (ARINC standards) as not yet having reached maturity. Boeing's efforts are customer driven – when they have customers for the system they will step up activity.

Summary of Strong Characteristics	Flexibility in concurrent use of a frequency for voice and data communications
Summary of Weak Characteristics	
Conclusion: feasibility, maturity & timescale	Technology is feasible. Outstanding certification questions to be answered and avionics available by 2005. Operational deployment in US 2009/2010 for voice, with data services to follow as needed

I.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Flexibility in concurrent use of a frequency for voice and data communications Standardisation is mature.
Summary of Weak Characteristics	Europe already has 8.33 kHz voice resulting in a significant delay before a replacement voice system is required in Europe. This means it will be some years before there is a need for the voice component of VDL3 in Europe. The system has very little support in Europe. Because of the likely need for 25 kHz guard bands with VDL3, there is great difficulty in finding frequencies for the system due to high frequency congestion in the Com band in Europe. Requires operational testing, and some European standardisation activity, prior to any European implementation.
Conclusion: feasibility, maturity & timescale	Technology is feasible. Outstanding certification questions to be answered and avionics available by 2005. Operational deployment in US 2009/2010 for voice, with data services to follow as needed

J VDL Mode 4

J.1 Introduction

J.1.1 VDL Mode 4 (VDL4) is a digital data link designed to operate in the VHF frequency band using one or more standard 25 KHz VHF communications channels. It is capable of providing both point-to-point and broadcast services between mobile stations, as well as between mobiles and fixed ground stations.

J.1.2 VDL4 has support in Europe, particularly from Sweden [271], Russia [272], Germany and Italy as well as some Low Cost Carriers and the General Aviation Community, but is not well supported in the US. Comm4Solutions propose a network of VDL4 ground stations for AOC[273]. The system has undergone significant development and demonstration in Europe, with particular emphasis so far on its ability to support ADS-B applications.

J.1.3 ATN services are included in the point-to-point services that VDL4 provides. Examples of the services provided by VDL4 are illustrated in the figure below[23].

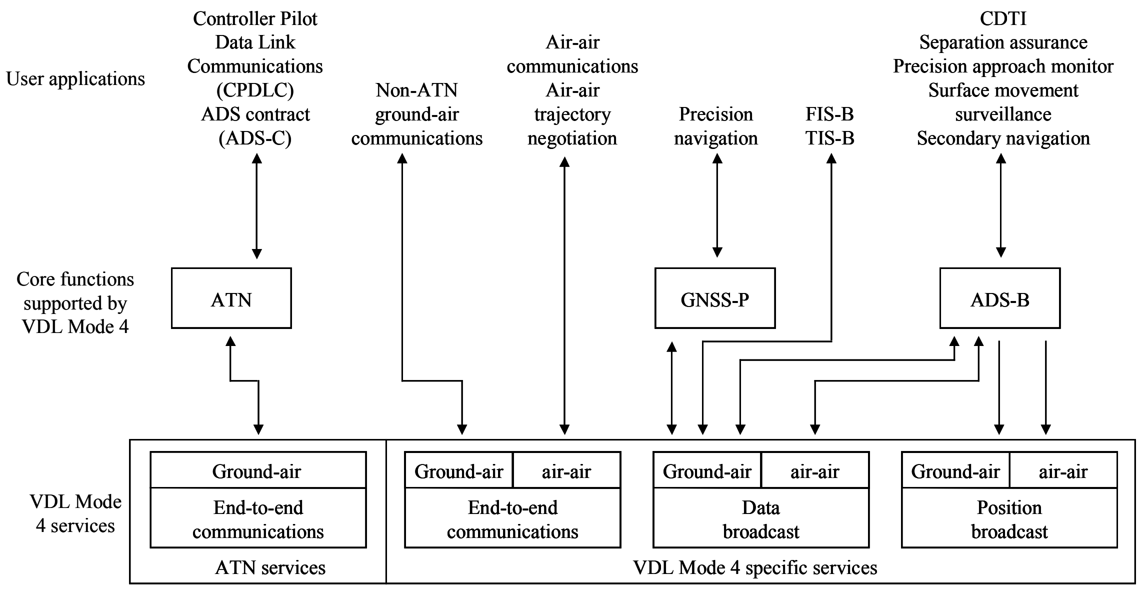


Figure J-1: VDL4 Services

System description

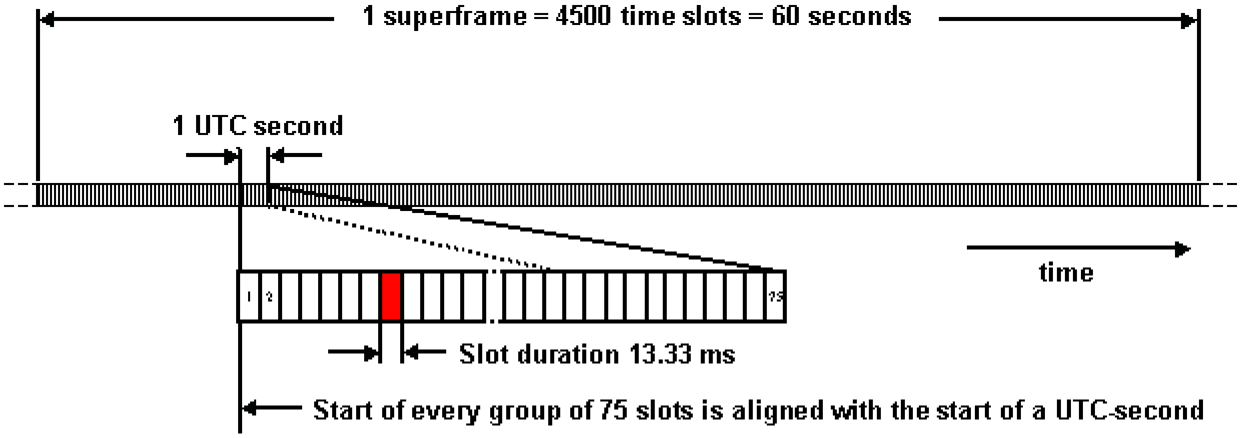
J.1.4 VDL4 uses the Gaussian-filtered Frequency Shift Keying (GFSK) modulation scheme which has a modulation rate of 19,200 bits/s.

J.1.5 Access to the VDL4 medium is time-multiplexed. The system uses the Self-organising Time Division Multiple Access (TDMA) concept, known as STDMA, which was invented and developed in Sweden.

[23] In addition VDL4 could be enhanced to provide a digital voice capability.

J.1.6 The STDMA scheme firstly divides the communication channel into 'time-slots'. Each time-slot may be used by a radio station (whether mounted on aircraft, ground vehicles or at fixed ground stations) to transmit a message.

J.1.7 Secondly, access to the time-slots is organised. This means that each station is responsible for prior selection and reservation of the slots it wishes to use. The use of organised time-slots reduces the chances of message conflict.



J.1.8 In order to transmit at the correct time and to ensure global co-ordination between all participating stations, each station requires an accurate time source. In VDL4, the time-slots are all synchronised to UTC time, normally provided by a GNSS receiver.

J.1.9 Slots are grouped into superframes, each 1 minute long, with 4500 slots in every superframe. Thus there are 75 slots per second, and each slot is 13.33 ms in duration.

J.1.10 A position report typically occupies one time-slot while other transmissions, such as ground station transmissions, may occupy more.

System operation

J.1.11 The self-organising concept allows VDL4 to operate efficiently without a centralised co-ordinating station, thus eliminating the need for a ground infrastructure. Ground stations may however serve an important role providing other services that enhance VDL4 operations.

J.1.12 VDL4 is foreseen to operate on specific channels, called Global Signalling Channels (GSCs), which should eventually be allocated worldwide. In high traffic-density airspace, the GSCs will be supplemented by Regional Signalling Channels (RSCs), or by Local Signalling Channels (LSCs). The GSC channels will be used by all participating stations, and used by ground stations to broadcast Directory of Services (DoS) information about the services available on the GSC channels, and on regional or local channels.

Effective Data Rate

J.1.13 The study team used a simplified simulator to analyse VDL4. The results obtained need to be seen in the context of the limitations of the simulator and will need further performance evaluation. The figures obtained for a 249 octet user data packet are about 14000 bps which applies to all regions. The reasons for the improvement relative to VDL2 are as follows:

- the access protocols allow all technical acknowledgements to be carried out in reserved slots - they are not subject to interference from random transmitters;
- the ground access protocols allow all uplink data to be carried in ground reserved slots;
- the access protocols allow all downlink data to be directed by a ground station into a ground reserved slot or at least into a reserved access slot;
- the use of the reservation protocols and ground reserved protocols means that hidden terminals are virtually removed - this makes the performance for long transmissions significantly better for long data transmissions;
- random access events are confined to single slot transmissions only and are completely excluded from ground reserved slots.

J.1.14 Overall these performance enhancements outweigh the negative impact of a lower data rate than VDL2 which uses 31.5 kHz. The difference between VDL2 and VDL4 is not as great for short user data packets (it is a factor of 2 for 50 octets of user data) - however, looking at the scenarios of interest, particularly for Step 4, the user data size is 100 or greater.

J.1.15 The action required from this is urgent confirmation of the performance of VDL2 and VDL4 for a European scenario via simulation.[24]

Frequency availability

J.1.16 Frequencies for VDL4 in Europe have been proposed by Eurocontrol. The plan foresees making way for the VDL frequencies at the top of the COM band and has been approved by the ICAO Frequency Management Group in Europe.

J.1.17 There is a debate as to whether VDL4 will be able to use frequencies in the NAV band. The FAA view is believed to be that VDL4 frequency assignments in the US would probably have to be in the COM band.

[24] During the public consultation process Eurocontrol provided an estimate of 12000 bps based on a correction to the ST15 report.

J.1.18 It is intended that VDL4 will operate on 25 KHz frequency channels in both the COM and NAV frequency bands.

Airborne terminal design

J.1.19 An investigation of the airborne architecture required for VDL4 is currently being undertaken by Honeywell as part of a Eurocontrol funded study. The results of this study are expected in January 2003[25].

J.1.20 Current European trials of STDMA equipment, such as NEAN, use a simple aircraft architecture based around a single box containing VHF data link and GPS receiver equipment.

J.1.21 A future VDL4 installation would be more complicated. It will require new equipment to be installed in the aircraft that could potentially replace existing VHF data link equipment or could be added as additional equipment. If it is additional equipment, then an additional VHF antenna will be required. This might be able to use existing antenna mounts or, if none are available, then new antenna mounts will be required.

J.1.22 The position information required to support VDL4 ADS-B reports would be supplied by the aircraft navigation system and avionics. Position and ground vector data could be obtained from a GNSS receiver and the barometric altimeter could provide altitude information. This data would be passed onto applications such as the CDTI (Cockpit Display of Traffic Information), which is used to display a surveillance picture of the surrounding traffic. Data is used for other surveillance functions if required and is also passed on to the transceiver for transmission in ADS-B reports. The VDL4 system would also require a source of UTC time, either provided by the aircraft avionics or from a separate GNSS receiver.

J.1.23 A data processing unit would also be part of the airborne architecture, processing ADS-B reports and data from external sources to provide surveillance reports for the CDTI and other applications.

J.1.24 For use of VDL4 for point-to-point applications, it expected that a Communications Management Unit (CMU) will be required.

Ground terminal design

J.1.25 The VDL4 system can operate in an environment without ground infrastructure as well as in an environment with a ground infrastructure. When no ground infrastructure is present, the system operates in its basic autonomous mode with only mobile units communicating on the two GSCs. The services supported are the ADS-B function and air-to-air communications. Adding a ground infrastructure, such as ground stations and a ground network, provides the opportunity to create more capacity and functionality in the system and to include ATS and other ground users and systems in a larger domain.

J.1.26 The ground architecture used for VDL4 applications must be able to receive and distribute time critical information to a large number of users. The architecture must also support uplink of information, sometimes time critical, over large areas.

[25] At time of writing (February 2003), draft material is available from this study [263] and is being commented on by stakeholders.

The security and reliability of the ground architecture must be high, even though different implementation levels are possible. The ground architecture consists of the basic elements shown below.

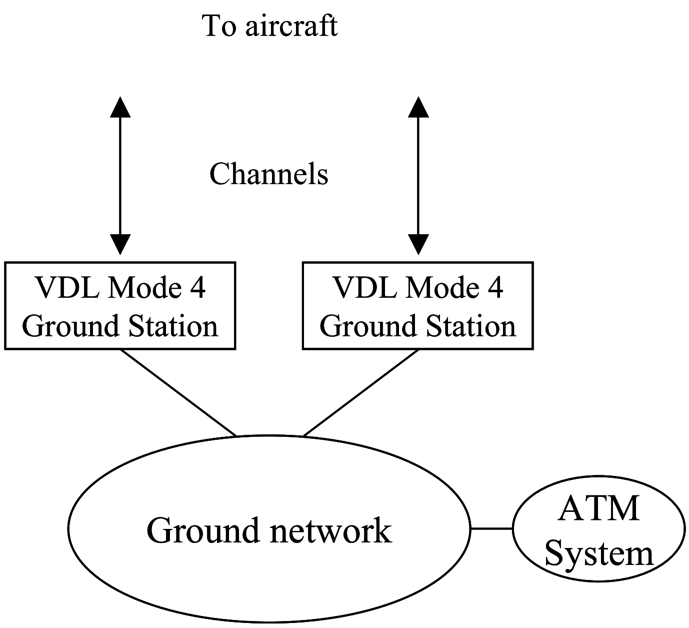


Figure J-2: VDL4 Ground Architecture

J.1.27 A single ground station antenna/transceiver will be capable of supporting the following functions:

- Acts as an ADS-B sensor in common with airborne units
- Provides TIS-B and FIS-B uplinks
- Provides a timing beacon to airborne users that can serve as backup timing.
- Provides time-of-arrival measurement of ADS-B transmissions for independent range measurement. Networked ground stations with overlapping coverage will allow surveillance based on the "multilateration" technique whereby a 2-D position is derived independently of the position reported via ADS-B.

Security Issues and Datalink Management

J.1.28 Since the 11th September event, aviation is specially focusing on security and safety issues, that involve ensuring confidentiality, authentication, integrity and availability of the communications service. The ATN addresses data-link security at the upper layers of the OSI stack and includes mechanisms for authentication and integrity of air-ground applications and IDRP communications as well as support for cryptology based on a Public Key Infrastructure (PKI). The currently defined data links do not however support security measures at the lower level. Best practice from military data-links suggests that improvements to safety and security can be achieved by including relevant mechanisms within the lower layers. In particular, knowledge of an aircraft's position, which is available within the VDL Mode 4 system, is of particular advantage in developing authentication functions, which would support all applications (ADS-C, ADS-B, CPDLC, conflict resolution etc).

J.1.29 The concept of ADS-B includes automatic transmission of intent and trajectory information, allowing receiving units to know about the actual intention of aircraft at an early stage. This function is supporting efficient and orderly flow management but it would also provide early warning and alarm in situations of unlawful activities.

J.1.30 An essential part of The VDL Mode 4 system is the independent timing function based on the possibility of range measurements, i.e. measuring how long time it takes for a message to travel from the transmitter to the receiver. As the transmission speed is equal to speed of light, the time can easily be transferred to distance to the transmitter making it possible to verify that position information in synchronisation bursts (used for data link management and ADS-B in VDL Mode 4) is correct, thus avoiding the risk for spoofing transmitters.

J.1.31 The ranging function can also be used as a complement and backup to GNSS. In the VDL All ground stations in the Mode 4 concept regularly transmits their position and accurate time together with an indication announcing if the particular ground station is certified for “secondary navigation”. Providing that “secondary navigation” is supported, all mobiles can use transmissions from these ground stations and calculate their actual position. This could form an extra safety net independent of GNSS and traditional ground based means for navigation.

J.1.32 Position information included in the VDL Mode 4 synchronisation bursts can also be used to optimise data-link management functions in a very efficient way, which would be applicable to all data link functions independent of it is used for surveillance or communication applications.

Standardisation

J.1.33 VDL4 SARPs were published by ICAO in late 2001. Work on updating the Technical Manual for improvement of point-to-point communications has recently been completed, and awaits publication by ICAO.

J.1.34 VDL4 ADS-B MOPS were published as Interim MOPS by EUROCAE in mid-2001. A European Norm for VDL4 ground stations has recently been produced by ETSI.

J.1.35 Work on specific AEEC standards for VDL4 has not yet started, but discussions are underway to initiate this activity.

Demonstration

J.1.36 Prototype STDMA/VDL4 equipment has been trialled in several projects, including:

- FARAWAY which considered the operational benefits of ADS, in particular from the fusion of radar surveillance data with ADS data from the aircraft;
- MAGNET B used to investigate the use of a VHF datalink to distribute local area GNSS augmentation signals;
- SNOWCARD looked at functions such as situation awareness, co-ordination and guidance in snow clearance at Arlanda airport;
- NEAN which demonstrated the possibility to use STDMA/VDL4 for CNS/ATM applications;

- NUP (NEAN Update Programme) providing a platform for ADS-B, differential GPS services and basic end-to-end communications (NUP Phase II) is currently ongoing).
- MEDUP is also deploying VDL4 ground stations in the Mediterranean region.

VDL4 has also been successfully demonstrated for surface applications:

- Gothenburg 1991-1994,
- Stockholm- Arlanda since 1998-,
- DEFAMME, MAGNET-B (Shiphol),
- Atlanta trials 1996-1998,
- Heathrow tests 2002.

Operational Use

J.1.37 A local implementation of STDMA/VDL4 for surface movement applications has been in operation since 1998 at Arlanda Airport, tracking ground vehicles for snow clearance operations.

J.2 References

J.2.1 The following key references define VDL4:

- Draft Manual on Detailed Specifications for the VDL Mode 4 Digital Link (Eurocontrol working draft post AMCP WG-M/2), Eurocontrol (ICAO), 21 January 2002 [29].
- Standards and Recommended Practices (SARPs) for VHF Digital Link, Annex 10, Volume III, Part I, ICAO [33].
- ED-108: Interim MOPS for VDL Mode 4 Aircraft Transceiver for ADS-B EUROCAE, July 2001 [78].
- Technical Link Assessment Report, Eurocontrol, March 2001 [15].
- Summary of the Functional and Technical Assessment of the ADS-B Link Architecture Alternatives, Interim Report, FAA, November 7 2001 [151].
- Simulation of ADS-B using VDL Mode 4 in the LA Basin and Core European Airspace, Swedish CAA, Version 3.0, June 1999 [150].
- VDL Mode 4 in A-SMGCS – Performance Simulations, LFV, January 2002 [154].
- ATC Simulation Report: Delegated Airborne Separation during Approach and Climb Out. May 2000, NUP, SATSA [134].

J.3 Technical Assessment

J.3.1 General Description

Parameter	Value	Notes
Service topology	Air-air broadcast Uplink broadcast Downlink broadcast Air-air point-to-point A/G point-to-point	
ATN compliance	Yes	
Frequency band	108-136.975 MHz	Allocations of required channels could be in either the COM or NAV bands. No global allocation has yet been determined. To support ADS-B applications VDL4, four channels are recommended 2 and 2 regional. Additional local channels would also be required for airport surface operation.
RF Channels	Multiple 25 kHz channels	
Modulation scheme	Binary GFSK +/- 2400 Hz	
Bit rate	19200 bit/sec	
Channel access method	STDMA	Self-Organising TDMA with nominally 75 slots per second per channel.

Parameter	Value	Notes
Frequency availability (allocation status)	Experimental frequency assignment exists in Europe. Earliest World/Europe-wide availability: 2006 Regional availability possible earlier	The deployment of VDL4 will require global, regional and local allocations of suitable frequencies. Depending upon the chosen role, four to seven 25 kHz channels will be required which could be in either the COM or NAV bands. International co-ordination at ITU-level will be required. The US is particularly concerned about the operation of VDL4 in the NAV band. Two Europe-wide regional frequencies have been proposed at ICAO Europe FMG for use at the top of the COM band for ADS-B – one GSC and one regional channel. Two further frequencies (one GSC and one regional) would be required for ADS-B, which could possibly be provided in the NAV band. Additional local channels may be required for ADS-B in high-density areas. Further additional channels would be required for TIS, FIS and other services. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there are no regulatory impediments against applying VDL Mode 4 as a data link supporting C, N and S applications.
Dependencies	UTC time source	Requires an accurate source of UTC time, nominally from a GNSS receiver (which may be a GPS receiver)

J.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Yes	VDL4 has been specifically designed to support multiple user profiles with QoS management.
Message length	192 bits for 1-slot message	Multislot messages may also be used, with a greater number of bits per message. The DLS (point-to-point) supports M-bit processing, hence any message length may be handled.
Transmission delay	1 second	Design criteria, simulations of new DLS are required to support this value.
Effective Data Rate	14 kbps per channel	See introduction.
Availability	TLAT: ADS-B supported by VDL4 will meet MASPS requirements for availability of service.	While transmitting, a VDL4 station may suppress its receive capability on other VDL 4 channels. This means that the station may miss one or more slots on another channel(s). While transmitting at a nominal rate of once per 20s on each GSC, this might result in 6 missed slots per minute (of the total 4500).
Integrity	1 in 2^{16}	TLAT report: A 16-bit cyclic redundancy check is added to each message. This reduces the probability of an undetected bit error in a message to 1 in 2^{16}. Other integrity checks may further reduce the overall undetected message error rate.
Continuity of function	TLAT: ADS-B supported by VDL4 will meet MASPS requirements for continuity of service	"The probability that the ADS-B System, for a given ADS-B Message Generation Function and in-range ADS-B Report Generation Processing Function, is unavailable during an operation, presuming that the System was available at the start of that operation, shall be no more than 2 x 10^{-4} per hour of flight. The allocation of this requirement to ADS-B System Functions should take into account the use of redundant/diverse implementations and known or potential failure conditions such as equipment outages and prolonged interference in the ADS-B broadcast channel."
Capacity	In broadcast mode 75 messages per second. 14000 bps per channel for point-to-point	Capacity is dependant upon update rate and range. See introduction for effective data rate calculation.
Coverage (airspace category) & Range	Range of 200 nm	
Priority management	Yes	All 15 ATN levels supported. High priority messages will pre-empt low priority messages.

J.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Completed for broadcast Partially completed for point-to-point	A large number of simulations have been conducted. The most commonly used simulator is the STDMA/VDL Mode 4 Performance Simulator (SPS). Eurocontrol have recently taken delivery of a new VDL4 simulator (VPS) which supports dynamic scenarios. Simulation work has shown that the two 25 kHz GSC channels plus two regional channels are required to support ADS-B in Europe.
R&D Trials	Partially completed for broadcast No activity for point-to-point	Significant activity for broadcast. No activity for point-to-point services. Significant demonstrations of VDL4 supporting air-air, air-ground and surface surveillance have been conducted in Europe, including: NEAN, NAAN, NUP MFF and MEDUP. A significant number of aircraft have been equipped with early VDL4 avionics. A number of VDL4 ground stations exist.
Pre-Operational Trials	Partially completed for broadcast No activity for point-to-point	
Operational Trials	Partially completed for broadcast No activity for point-to-point	A local implementation of STDMA/VDL4 for surface movement applications has been in operation since 1998 at Arlanda Airport, tracking ground vehicles for snow clearance operations.
Other Systems	STDMA which is the basis of VDL4 is also the basis for AIS which is used by the marine community.	The maritime sector started the standardisation of the maritime version of VDL Mode 4 – the Automatic Identification System (AIS)- in 1996. Standards have been adopted by ITU and IMO, the AIS system is mandatory for so-called SOLAS ships and decisions have been made to implement a European wide network of AIS ground stations. For security reasons the US President in December 2002 signed a Directive stating that all boats in US costal and inland waters with a length exceeding 8 meters shall be equipped with AIS before the end of 2004.
Standards Development		

ICAO	SARPs published Mature draft of Technical Manual available	ICAO Annex 10 SARPs for VDL4 were published November 2001 - VDL4 currently accepted for surveillance only according to ICAO SARPs. Point-to-point amendments have been drafted and validated: ICAO Manual on Detailed Technical Specifications for VDL Mode 4 is in the process of being updated to enhance the point-to-point functionality offered by VDL4. This work is expected to be finished by August 2002. Publication of the Manual is expected by the end of 2002. Approval for use for communications services expected at AMCP/8 in early 2003.
EUROCAE/RTCA	EUROCAE MOPS published as Interim MOPS	EUROCAE MOPS for VDL Mode 4 ADS-B were published as Interim MOPS in June 2001. The test cases in the EUROCAE MOPS require validation.
AEEC	Activity not yet started	Work on specific AEEC standards for VDL4 has not yet started, but discussions are underway to initiate this activity
ETSI	Published	ETSI have published in August 2002 a European Norm for VDL4 ground stations. Phase 2 of the ETSI work will address point-to-point communications.
Other Standards	AIS Standards	The maritime sector started the standardisation of the maritime version of VDL Mode 4 – the Automatic Identification System (AIS)- in 1996. Standards have been adopted by ITU and IMO.
Conclusion	Complete for broadcast Point-to-Point amendments required	
Equipment Development		
Prototype airborne equipment status	Available	A significant number of aircraft have been equipped with early VDL4 avionics.
Red-label (operationally capable) airborne equipment status	Available	SARPs-compliant airborne radios are commercially available for ADS-B use from CNS Systems.
Certification	Available	Sweden have issued CNS with a Type Certificate (for GA aircraft). CNS expect to have their AT radio certified by April 2003.
Conclusion	Nearly Available	Some equipment is available, the large manufacturers are showing interest but not commitment.

Prototype ground equipment status	Available	A number of prototype VDL4 ground stations exist, many being part of the NUP programme.
Operationally capable ground equipment status	Available	SARPs-compliant ground radios are commercially available for ADS-B use from CNS Systems.
Certification	No known issues	
Conclusion	Nearly Available	
System Deployment		
Ground deployment plans status	Pre-operational deployment under NUP Com4Solutions proposed ground network for AOC	Avionics and ground stations available
Aircraft fleet equipment plans status	No known plans	Easyjet and SAS support VDL4 in principle - no firm plans have been announced.
Mandatory Carriage Status	No	No mandate is envisaged
Conclusion	Potential Deployment	

J.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Requires connection to an accurate source of UTC time. Interference with other onboard VHF systems must be avoided. Requires additional use of existing onboard antennas. Eurocontrol launched a 7 month study in June 2002 to investigate the airborne architecture of VDL4.
Ground architecture	Requires connection to an accurate source of UTC time.

J.4 Cost Assessment

J.4.1 Ground Costs

J.4.1.1 Ground costs with VDL4 used for both point-to-point and broadcast

Specific equipment and operations	Value (euro)	Notes
Hardware		
Cost of VDL4 ground station	150,000	[229]
Installation	2,500	[229]
Total initial cost per ground station (1 transceiver)	**152,500**	
Yearly maintenance costs per ground station (1 transceiver)	15,000	10% initial hardware cost
Number of ground stations required	150	

J.4.1.2 Ground costs with VDL4 used for point-to-point only

Specific equipment and operations	Value (euro)	Notes
Hardware		
Cost of VDL4 ground station	120,000	[229]
Installation	2,500	[229]
Total initial cost per ground station (1 transceiver)	**122,500**	
Yearly maintenance costs per ground station (1 transceiver)	11,000	10% initial hardware cost
Number of ground stations required	150	

J.4.1.3 Ground costs with VDL4 used for broadcast only

Specific equipment and operations	Value (euro)	Notes
Hardware		
Cost of VDL4 ground station	120,000	[229]
Installation	2,500	[229]
Total initial cost per ground station (1 transceiver)	**122,500**	
Yearly maintenance costs per ground station (1 transceiver)	12,000	10% initial hardware cost
Number of ground stations required	150	

J.4.2 Airborne Costs

J.4.2.1 Airborne costs with VDL4 used for both point-to-point and broadcast

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of VDL4 transceiver	45,000[26]	[38]
Antenna (x 2)	2,000	[38]
GPS antenna	1,500	[38]
CDTI (x 2)	68,000	[38]
CMU	47,000	[218]
Upgrade of FMS	68,000	[38]
Integration, installation & certification		
Installation kit(s)	12,150	5% equipment cost
Service bulletin	24,300	10% equipment cost
Man-hours (80 euro/hour)	12,150	5% equipment cost
Operations & maintenance training		
Crew (6 crew) simulator training	77,000	[38]
Crew (6 crew) theoretical training	4,000	[38]
Simulator modification	8,000	[38]
Total initial costs per aircraft (1 transceiver)	**369,100**	
Yearly maintenance costs per aircraft (1 transceiver)	24,300	10% initial hardware cost

[26] CNS Systems indicated that the price for production units would be between €30,000 to €45,000, the higher value has been used. Low run units developed for NUP cost €50,000

J.4.2.2 Airborne costs with VDL4 used for both point-to-point and broadcast

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of VDL4 transceiver	45,000	[38]
Antenna (x 2)	2,000	[38]
GPS antenna	1,500	[38]
Upgrade of CDTI (x 2)	10,000	Estimate
Upgrade of CMU	8,000	[216]
Integration, installation & certification		
Installation kit(s)	3,900	5% equipment cost
Service bulletin	7,800	10% equipment cost
Man-hours (80 euro/hour)	3,900	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**82,100**	
Yearly maintenance costs per aircraft (1 transceiver)	7,800	10% initial hardware cost

J.4.2.3 Airborne costs with VDL4 used for point-to-point functions only (baseline VDL2/1090 ES)

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of VDL4 transceiver	45,000	[38]
Antenna (x 2)	2,000	[38]
Upgrade of CMU	8,000	[216]
Integration, installation & certification		
Installation kit(s)	3,325	5% equipment cost
Service bulletin	6,650	10% equipment cost
Man-hours (80 euro/hour)	3,325	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**68,300**	
Yearly maintenance costs per aircraft (1 transceiver)	6,650	10% initial hardware cost

J.4.2.4 Airborne costs with VDL4 used for broadcast functions only

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of VDL4 transceiver	45,000	[38]
Antenna (x 2)	2,000	[38]
GPS antenna	1,500	[38]
Upgrade to CDTI (x 2)	10,000	Estimate
Integration, installation & certification		
Installation kit(s)	3,500	5% equipment cost
Service bulletin	7,000	10% equipment cost
Man-hours (80 euro/hour)	3,500	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**73,000**	
Yearly maintenance costs per aircraft (2 transceiver)	7,000	10% initial hardware cost

J.5 Industrial Assessment

J.5.1 Stakeholder Support

Parameter	Issues
Europe	Support in Europe, Russia, Sweden
FAA	No support
Comm4Solutions	Proposed ground network to support AOC
Easy Jet	Easy Jet have publicly supported VDL 4 at ATN2002

J.5.2 Vendor Perspective

Parameter	Issues
ADSI (USA)	ADSI have contributed to VDL4 development within the ICAO and EUROCAE frameworks. They are manufacturers of prototype VDL4 radio equipment.
CNS Systems (Sweden)	CNS Systems develop and manufacture VDL4 airborne and ground stations for aviation, and also manufacture radios for marine applications. CNS Systems hold a Type Certificate for VDL4 Avionics.
Transpondertech (SAAB)	SAAB Transpondertech have contributed to VDL4 development within the ICAO and EUROCAE frameworks. They have prototype VDL4 equipment. Currently they produce STDMA/VDL4 equipment for an ADS-B system for the marine environment.
Honeywell	Honeywell have a limited amount of internal activity. They have produced a white paper regarding the integration of VDL4 with other avionics on board the aircraft. Honeywell are currently conducting a study for Eurocontrol which is examining the feasibility of an airborne architecture for VDL4. The results of this study are expected in January 2003. Frequency planning is seen as an important issue.
Rockwell Collins	VDL4 is under development within Rockwell Collins. The company has recently been selected for production of prototype VDL4 development and the contract award is in process.
Telerad (France)	Telerad are manufacturers of VDL4 radio equipment.
GP&C Global Support Ltd. (GGS) (Denmark)	GGS are manufacturers of VDL4 airborne and ground stations. for aviation use. One GGS delivered system is certified in Peru. GGS produces data link equipment for maritime use."
Marconi Selenia Communications	Competitive and cost effective communications services could be deployed in a 2 years time frame also using VDL4. This solution is already of interest of several airlines today, and we as a leader communication Industry can fully confirm its feasibility.

J.5.3 Airframer/Integrator Perspective

Parameter	**Issues**
Boeing	Boeing has no activity in relation to VDL4. Boeing's efforts are customer driven – when they have customers for the system they will initiate activity.
Airbus	Airbus has contributed to VDL4 development and to ADS-B application development as a participant in the NUP Programme. Previous work has included development of an ADS-B airborne architecture for VDL4. Currently, Airbus has significant interest in developing the ADS-B datalink applications, but only a background activity in the VDL4 technology.

J.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Provides both a broadcast and a point-to-point service in one system. For point-to-point communications, effective data rate is estimated as 14 kbps. The system has support in Europe. Many trials have been performed. Standards and equipment are fairly mature. Range and throughput are sufficient to support a significant number of broadcast and point-to-point applications in the medium term. Security features in the future CNS/ATM systems have to be addressed. They will require a two-way data link capability. Several such features are being implemented in the maritime AIS (VDL Mode 4-like) systems and that could also be done in the VDL Mode 4 aviation systems.
Summary of Weak Characteristics	Lack of maturity for point-to-point application. AMCP/8 accepted the latest version of the DLS (point-to-point) protocol subject to successful flight trials. For broadcast, it suffers from low capacity (eg only 75 slots per second), and requires complex channel management. Compatibility (interference) with other airborne systems is still being investigated and is considered a serious issue. Frequency planning criteria need to be established.
Conclusion: feasibility, maturity & timescale	VDL Mode 4 was developed as a generic communications system supporting all the three disciplines of C(ommunication), N(avigation) and S(surveillance). The ICAO standard was originally approved for surveillance applications. At AMCP/8 in February 2003 it was decided to recommend to ICAO to make VDL Mode 4 applicable to communication applications as well. The aviation position for agenda item 1.28 at the World Radio Conference in June 2003 (WRC-2003) deals with allocation of navigation and surveillance services supported by data links in the band 108-118 MHz and it is expected that the WRC-2003 will decide in accordance with the aviation position. Subsequently there are no regulatory impediments against applying VDL Mode 4 as a data link supporting C, N and S applications. As a broadcast technology, VDL4 is rapidly reaching sufficient maturity for operational use. It is estimated that deployment could be widespread by 2006, but this is critically dependent on VHF frequency availability.

K UAT

K.1 Introduction

K.1.1 The Universal Access Transceiver (UAT) is the result of an internally funded project at MITRE/CAASD in the US, started in December 1994 to develop and demonstrate a transceiver system designed specifically to support the function of ADS-B. UAT has been developed to a prototype status and has been flown in flight trials in the US.

K.1.2 In addition to ADS-B, UAT is intended to support uplink broadcast data from ground stations. This could include TIS-B and/or FIS-B data. UAT is only intended to support broadcast applications.

K.1.3 The UAT prototype operates in a single channel with a bandwidth of approximately 2-3 MHz, using the same frequency for transmit and receive. All aircraft access the channel autonomously at random, and there is no centralised ground control or on-board logic for this function.

K.1.4 The first UAT prototype operated with experimental authorisation at 966MHz, which is in the range used for DME (960-1215 MHz). The large scale trials presently underway in Alaska (“Capstone”) operate at 981 MHz. The channel that will be used in a final operational system is not yet fixed. Within the US, the FAA has initiated procedures to secure a permanent frequency assignment.

K.1.5 UAT has been specifically designed to provide air-air, air-ground and ground-air broadcast services.

K.1.6 UAT does not provide point-to-point functionality.

System description

K.1.7 UAT messages are transmitted using continuous phase frequency shift keying. Data is transmitted at a rate just over 1 Mbit/sec (precisely 1.041667 megabit/second), thus each bit period is 0.96 microseconds.

K.1.8 In the UAT system, the ‘frame’ is the most fundamental time unit. Frames are one second long and begin at the start of each UTC (or GNSS) second. Each frame is divided up into two segments – one for ground station transmissions and another for mobile station transmissions (aircraft or surface vehicle).

K.1.9 Each segment is further subdivided into message start opportunities (MSOs) spaced 250 ms apart for a total of 4,000 MSOs per frame. The MSO is the smallest time increment used for scheduling Ground Uplink messages or ADS-B message transmissions.

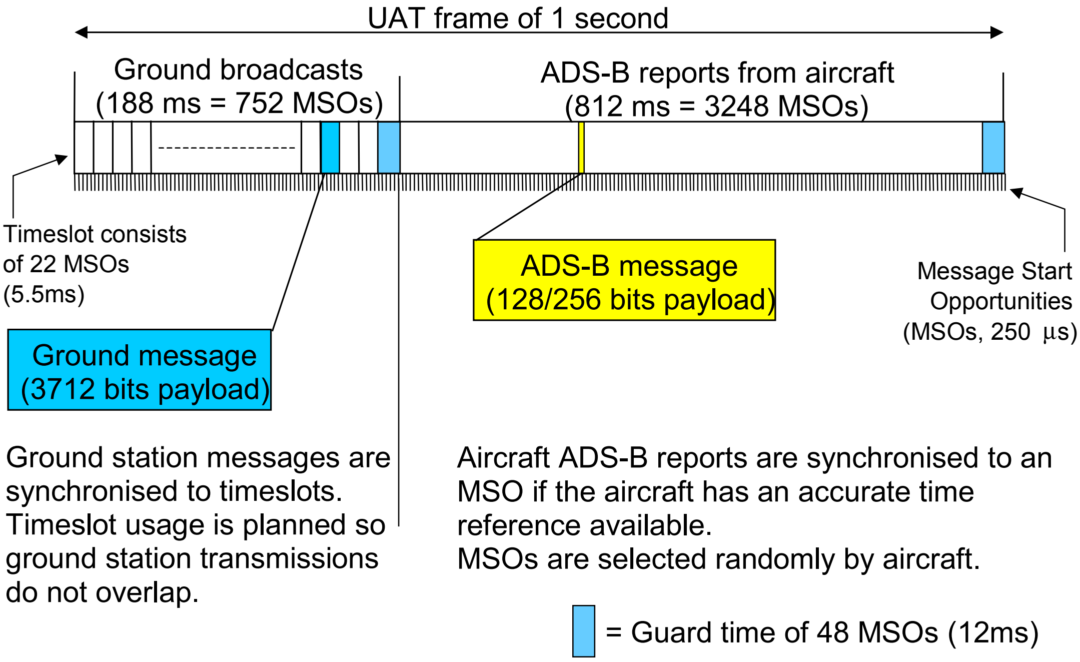


Figure K-1: UAT timing structure

Ground transmissions

K.1.10 The first segment of the frame is allocated to transmissions from UAT ground stations and consists of 752 MSOs (Message Start Opportunities). This portion of the frame contains 32 time-slots, each containing 22 MSOs and therefore lasting 5.5 ms, with a guard time of 48 MSOs at the end of the frame.

K.1.11 Each ground station is assigned one of the 32 time-slots in such a way that nearby ground stations can be received without interference. Each ground station transmits a ground broadcast message once each second, starting at the beginning of its assigned slot.

ADS-B message transmissions

K.1.12 The second segment of the frame is devoted to ADS-B message transmissions. Within this portion of the frame, aircraft and surface vehicles are required to transmit at randomly selected times from among the 3200 MSOs in the segment. The selection algorithm is designed to prevent any two stations from repeatedly selecting the same MSO. Aircraft messages may contain 128 or 256 bits of ADS-B data (payload).

K.1.13 A substantial guard time, specifically for timing drift, is accommodated at both the beginning and the end of an ADS-B segment. This allows for clock drift in airborne units for a period of time before there would be any possibility of ADS-B transmission overlap with a ground message.

K.1.14 UAT, like VDL4, needs a source of precise time to ensure that it is aware of the timeslot structure to which it should adhere when transmitting messages. The source could most easily be a GNSS receiver. However, in the event of loss of the timing source, a mobile UAT receiver may make timing measurements on ground station signals to determine timing information.

K.1.15 Exactly one ADS-B message is transmitted per aircraft every second. An ADS-B message is either 252 or 380 bit intervals in length. Figure K-2 shows the format and components of the ADS-B message burst transmission from aircraft (or ground vehicles).

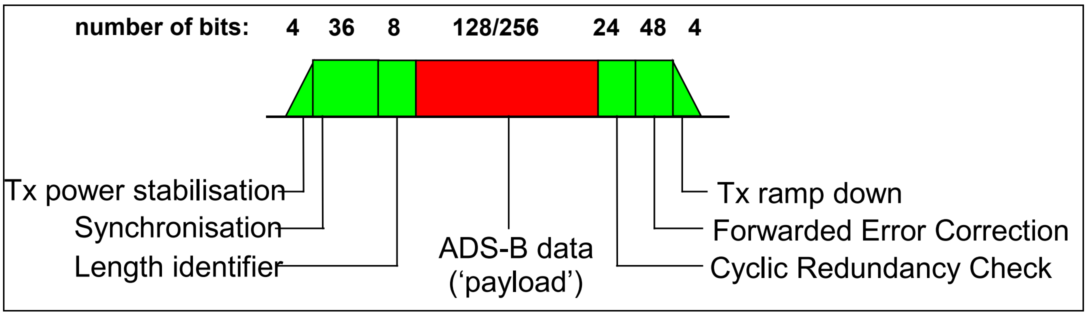


Figure K-2: UAT ADS-B message transmitted from aircraft/ground vehicle

K.1.16 UAT is the only one of the ADS-B data link systems to incorporate a Forward Error Correction (FEC). This gives it increased robustness to bit errors that may occur in the message since a small number of these can be corrected. The Cyclic Redundancy Check (CRC) is still applied following any corrections by the FEC. This maintains the integrity of the message.

K.1.17 The UAT message set is defined with a "Basic" Message that includes only State Vector information, and a set of 3 "Extended Length" Messages (types 0, 1, 2) that each include the State Vector plus other variable information required by the RTCA MASPS (DO-242). In trials (e.g. the Capstone trial), aircraft were configured to only transmit the basic and extended type 0 messages.

K.1.18 The ADS-B message transmission rate for UAT is fixed at once per second. This rate has been designed to support all applications identified in RTCA DO-242.

Airborne terminal design

K.1.19 Different airborne terminal configurations are possible depending on the class of aircraft. The configuration in Figure K-3 may be sufficient for low-end general aviation users

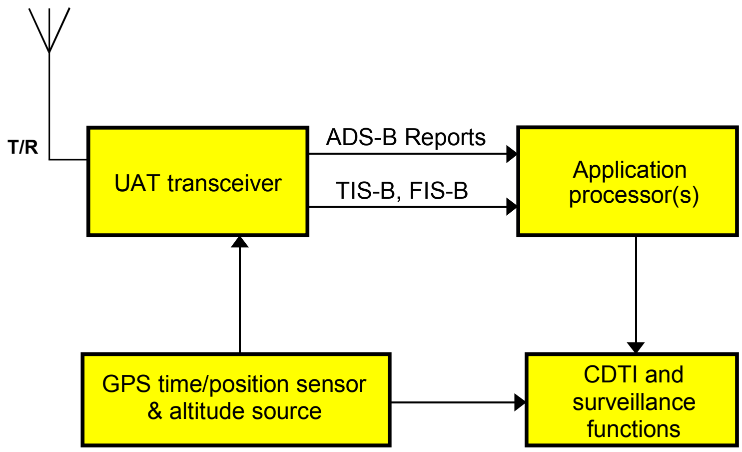


Figure K-3: UAT Low-end airborne architecture

K.1.20 A processing unit linked to the transceiver processes data from ADS-B reports and external data sources such as TIS-B and FIS-B, and provides surveillance reports and track data to the CDTI and other surveillance functions.

K.1.21 Under normal conditions it is expected that the UAT transceiver would interface with a GNSS sensor and barometric altitude source for a minimal installation. The GNSS sensor would provide the position and velocity information as well as timing for ADS-B transmissions. These sources of aircraft data would also provide information to the CDTI and other surveillance functions about the aircraft's own position and status.

K.1.1.1.1 Air transport category aircraft may carry dual UAT transceivers, each connected to the application processor(s) and the GNSS time/position and altitude sources.

Ground terminal design

K.1.22 The ground subsystem will operate as an ADS-B sensor identically to that of airborne units. The ground subsystem will additionally be capable of transmitting FIS-B and TIS-B uplinks.

K.1.23 The ground station antenna is likely to be a 6-8 dBi omni-direction antenna of DME-style. Figure K-4 gives an overview of the ground station architecture.

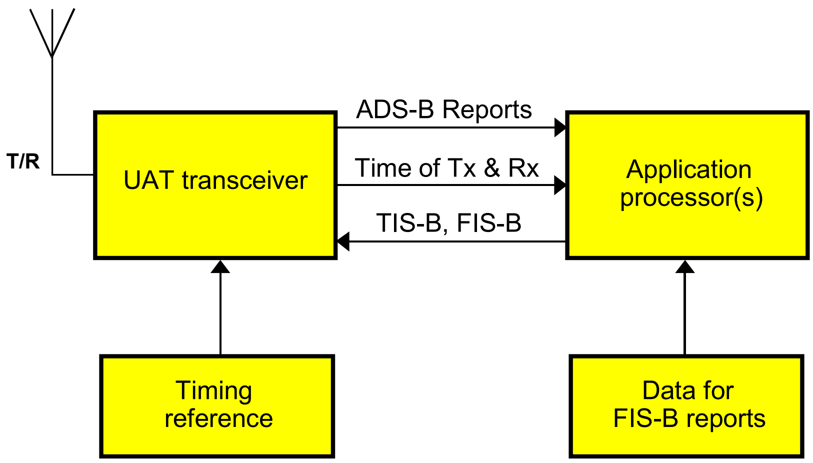


Figure K-4: UAT Ground station architecture

K.1.24 A single ground station antenna/transceiver will be capable of supporting the following functions:

- Acts as an ADS-B sensor in common with airborne units
- Provides TIS-B and FIS-B uplinks
- Provides a timing beacon to airborne users that can serve as backup timing.
- Provides time-of-arrival measurement of ADS-B transmissions for independent range measurement. Networked ground stations with overlapping coverage will allow surveillance based on the "multilateration" technique whereby a 2-D position is derived independently of the position reported via ADS-B.

Standardisation

K.1.25 RTCA UAT MOPS has recently been completed.

K.1.26 An AMCP Working Group of the Whole meeting in May 2002 decided to initiate SARPs development of UAT, a move supported by the FAA.

K.1.27 AEEC standardisation has not been initiated. We are unaware of any standards activity for UAT ground stations.

Demonstration

K.1.28 TLAT and subsequent simulations have shown that UAT is able to meet all ADS-B requirements (except that surface applications have not been evaluated).

K.1.29 The FAA conducted initial trials of UAT in the Ohio Valley, known as OpEval, as part of the FAA's Safe Flight 21 programme. This work was reported in two phases, OpEval-1 and OpEval-2. FAA trials are continuing with the Alaska Capstone programme.

K.1.30 Capstone is a joint initiative between the FAA and US industry. It is evaluating ADS-B applications through trials conducted in the Alaska region. There are 150 aircraft equipped with UAT avionics including: GNSS navigation receiver, ADS-B transmitter/receiver, moving map display with TIS-B traffic and terrain advisory services, FIS providing weather maps etc. and a multi-function colour display

(CDTI). There is a network of 12 ground stations providing redundant coverage of ground stations. UAT is also being used to provide radar-like services.

K.1.31 A UAT trial was conducted in Paris in October 2000, organised by Eurocontrol with the participation of the FAA Safe Flight 21 Programme, Mitre, and UPS Aviation Technologies. UAT operation was tested in the 966 MHz channel, which is currently unused in France.

K.2 References

K.2.1 The following key references define UAT:

- Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance Broadcast (ADS-B), RTCA Paper No. 098-02/SC186-195 Prepared by: SC-186, WG-5, Drafted for Plenary Review May 2002 [143].
- Technical Link Assessment Report, Eurocontrol, March 2001 [15].
- Summary of the Functional and Technical Assessment of the ADS-B Link Architecture Alternatives, Interim Report, FAA, November 2001 [151].
- An analysis of the costs and benefits of ADS based on operational case studies - Results of Stage 1 ADS Programme CBA, Edition 0.4, Eurocontrol, September 2001 [38].
- OpEval Final Report, OpEval Coordination Group (OCG), April 2000 [145].
- OpEval-2 Final Report, OpEval Coordination Group (OCG), August 2001 [146].
- ADS-B Data Link Analysis: UAT in the 2015 Core European Scenario, Helios Technology, UAT-WP-11-22 (RTCA SC-186, WG-5) [132].
- Feasibility of finding UAT frequencies in the ARNS-Band 960-1215 MHz within the core area of Europe, DFS, AMCP WGW/WP21, May 2002 [137].
- UAT Performance in the presence of DME/TACAN and JTIDS/MIDS, John Hopkins APL, AMCP/WGW/WP16, May 2002 [153].
- Results on the utilisation of the frequencies 978 and 979 MHz in Europe, Eurocontrol, UAT-WP-5-15 (RTCA SC-186 WG-5) [147].
- FAA Issues STC for UPS Aviation Technologies ADS-B System on Boeing 757-200, UPS Aviation Technologies, May 2001 [252].

K.3 Technical Assessment

K.3.1 General Description

Parameter	Value	Notes
Service topology	Air-air broadcast, Uplink broadcast, Downlink broadcast	
ATN compliance	No	
Frequency band	960-1215 MHz	Currently no frequency globally available
RF Channels	Single 1 MHz channel	
Modulation scheme	Binary GFSK +/- 312.5 kHz	
Bit rate	1.041667 Mbit/s	
Channel access method	Random Slots	Ground Stations use separate slots in a predefined manner.
Frequency availability (allocation status)	No operational frequencies currently allocated. Earliest availability: 2006 (may be longer in Europe)	Europe and US are converging on the 978 MHz frequency. Analysis shows that a UAT assignment at 978 or 979 MHz is possible in the US. These frequencies are used in the US for testing purposes, and there are no operational assignments in that US at either frequency. Analysis of the utilisation of the frequencies 978 and 979 MHz in Europe shows that a number of DME and TACAN assignments exist in Europe at these frequencies: 6 assignments at 978 MHz and 50 assignments at 979 MHz, suggesting 978 MHz as a possible candidate for UAT. The deployment of UAT requires international co-ordination to obtain a 3MHz channel in the DME band. Whilst a suitable frequency seems likely to be available in America, the European situation is more complex. The ECAC Navigation Strategy foresees the long-term use of DMEs to support GNSS in providing a harmonised area navigation (RNAV) environment. This will require significant deployment of new DMEs in Europe, in particular within terminal areas. The current estimate is that 180-200 new DMEs will be required by 2010.
Dependencies	UTC time source	Requires an accurate source of UTC time, nominally from a GNSS receiver (which may be a GPS receiver)

K.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	No	
Message length	246 bits (short) 372 bits (long)	ADS-B messages lengths are 128 bits (short) or 256 bits (long)
Transmission delay	Minimal	Line of Sight propagation delay
Availability	Not Known	
Integrity		CRC and FEC
Continuity of function	Not Known	
Capacity	High	Supports all TLAT Evaluation Scenarios No data is known for surface performance
Coverage (airspace category) & Range	100 nm	
Priority management	Limited	Emergency/Priority status included in Type 0 Extended message type.

K.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Complete	UAT is strongly supported within the US, particularly by the FAA. Support for the system is limited outside the US.
R&D Trials	Complete	Several FAA trials
Pre-Operational Trials	Complete	In addition, Eurocontrol sponsored a trial of UAT. Trial equipment only exists for avionics and ground stations. Earliest availability for operational equipment is 2006.
Operational Trials	Complete	The FAA have supported several UAT trials, including: Capstone Alaska, Operational Evaluations in Ohio Valley.
Standards Development		
ICAO	SARPs activity initiated May 2002.	SARPS: AMCP WGW decided on 24th May 2002 that UAT SARPS should be developed. Historically the development of SARPS takes between 5 and 15 years. It is anticipated that UAT SARPS should be reasonably quick to develop and validate. It is estimated that the process will take 3 to 5 years
EUROCAE/RTCA	Published	MASPS exists for ADS-B and TIS-B. Technology dependant MASPS are not required. RTCA MOPS: RTCA DO-282 was published 27th August 2002. No EUROCAE Activity
AEEC	No activity	AEEC standardisation has not yet been initiated.
ETSI	No activity planned	
Other Standards	None	
Conclusion	Complete	
Equipment Development		
Prototype airborne equipment status	Prototype airborne equipment available	Manufacturers are UPS Aviation Technologies
Red-label (operationally capable) airborne equipment status	None	
Certification	No known issues	UPS Aviation Technologies has a Supplemental Type Certificate for the Boeing 757-200 for an ADS-B system (used in trials), which combines UAT with 1090 ES.
Conclusion	Mature	

Prototype ground equipment status	Prototype ground equipment available	Ground stations for FAA Safe Flight 21 and Cargo Airline Association OpEval-2 trials, combining UAT and 1090 ES were manufactured by Sensis Corporation.
Operationally capable ground equipment status	No operational systems in place	
Certification	No known issues	
Conclusion	Nearly Mature	
System Deployment		
Ground deployment plans status	Deployment planned by the FAA	Support for GA only
Aircraft fleet equipment plans status	Deployment planned by the FAA	Support for GA only
Mandatory Carriage Status	No	No mandate has been proposed
Conclusion	Deployment planned by the FAA	

K.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Requires connection to an accurate source of UTC time.
Ground architecture	Requires connection to an accurate source of UTC time.

K.4 Cost Assessment

K.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of UAT ground station	75,000	[38]
Installation	15,000	20% equipment cost
Total initial cost per ground station (1 transceiver)	**90,000**	
Yearly maintenance costs per ground station (1 transceiver)	7,500	10% initial hardware cost
Number of ground stations required	150	
Total ground station cost (1 transceiver)	**13,500,000**	

K.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of UAT transceiver	56,500	[38]
GPS antenna	1,500	[38]
Upgrade of CDTI (x 2)	10,000	Estimate
Integration, installation & certification		
Installation kit(s)	3,400	5% equipment cost
Service bulletin	6,800	10% equipment cost
Man-hours (80 euro/hour)	3,400	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**81,600**	
Yearly maintenance costs per aircraft (1 transceiver)	6,800	10% initial hardware cost

K.5 Industrial Assessment

K.5.1 Stakeholder Support

Stakeholder	Comments
FAA	UAT is strongly supported within the US, particularly by the FAA.
Eurocontrol	Support for the system is limited outside the US.

K.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell are monitoring the development of UAT, and following the progress of the MOPS (and SARPs). At the moment they see a lack of acceptance of the technology rather than a lack of maturity. If the market shows a demand for UAT they will develop a product. Frequency availability, particularly outside of the US is seen as an issue.
Rockwell Collins	Rockwell Collins is evaluating several UAT link options as part of the FAA dual link decision for ADS-B related applications.
UPS Aviation Technologies	UPS AT have UAT equipment available

K.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	No activity
Boeing	Boeing sees UAT as mainly a system for General Aviation aircraft. It has no dedicated activity with respect to UAT at the present time.

K.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	High data throughput performance means that the system can support a wide range of broadcast applications.
Summary of Weak Characteristics	Development of ICAO standardisation has only recently begun and will take some years. Some European standards are also likely to be required. Clearing of DMEs from a suitable frequency in Europe could be problematic, particularly if Europe decides that more DME stations are required. System is limited to broadcast applications only. UAT does not support the requirements of long range applications or support the full number of TCPs required by the MASPS. Support and expertise is limited in Europe.
Conclusion: feasibility, maturity & timescale	System approaching maturity. The FAA have selected UAT to support ADS-B applications for general aviation. UAT promises to be a capable broadcast media. However, the lack of maturity in terms of standards development is a concern, as is the availability of a suitable frequency in Europe. It is estimated that UAT could not be considered for operational use in Europe before 2006, and it may be longer since it depends on several factors being resolved quickly: SARPs completion, frequency availability and equipment availability.

L Gatelink

L.1 Introduction

L.1.1 The concept of high bandwidth communications with aircraft at or near the gate is not new. Over the years a number of technologies have been considered including the use of fibre-optic links, microwave links and more recently the currently emerging Wireless Local Area Network (WLAN) solutions.

L.1.2 A number of airlines and equipment manufacturers have shown considerable interest in the Gatelink concept. In particular the Rockwell-Collins Integrated Information System (I^2S) programme supports the integration of gatelink to multiple aircraft systems, a file server and a secure interface unit to enable safety and non-safety applications to be supported.

L.1.3 British Airways, Swissair and Condor have all been involved in trials of gatelink systems.

L.1.4 In 2000, Eurocontrol published an in depth study into Wireless Airport Communications Systems (WACS), which considered potential WLAN solutions for Gatelink. The material in this Annex is largely taken from the published reports. [11, 12, 192, 193, 194 and 179]

L.1.5 The three main Wireless LAN candidate technologies which could be used for Gatelink are:

- Systems operating at 2.4GHz conforming to IEEE 802.11b standards:
  - 2.4 GHz FHSS / DHSS
  - 2.4 GHz DSSS HDR
- High Performance Radio Local Area Network (HiperLAN) according to ETSI HiperLAN standards:
  - 5.2 and 5.8 GHz HiperLAN/1 and HiperLAN/2
  - 17.1 GHz HiperLAN
- Systems conforming to Digital European Cordless Telecommunications (DECT) standards.

L.1.6 Trials already conducted have shown that 2.4 GHz technology is usable in an airport environment using either DSSS or FHSS modulation. Systems operating at 5 and 17 GHz are less well developed. While these systems have the potential to offer improved data throughput, they do so at the expense of usable range.

L.1.7 Gatelink offers a huge potential for Airline Operational Communications (AOC), Airline Administrative Communications (AAC) and Air Passenger Correspondence (APC). The role in Air Traffic Control is less clear.

L.1.8 The deployment of Gatelink to support non-safety services is likely to be driven by local business cases and may support emerging Collaborative Decision Making (CDM) applications and applications involving the (re)allocation of CFMU slots, but the additional burden of supporting ATC is likely to increase costs and timescales.

The adoption of a mature system, some years after deployment, to support ATC in the presence of alternative communications means should be considered.

System description (2.4 GHz)

L.1.9 Systems operating at 2.4 GHz can either use Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS) modulation schemes. Current FHSS systems have a data rate of between 1 and 2 Mbps. Current DSSS systems have a data rate of 2 Mbps, but future systems are planned with a rate of up to 11 Mbps.

L.2 References

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L.3 Technical Assessment

L.3.1 General Description

Parameter	Value	Notes
Service topology	Uplink point-to-point, Downlink point-to-point	
ATN compliance	No	Current systems being implemented are based on TCP/IP and are not ATN compliant. The ICAO ATN Manual contains provisions for previous Gatelink solutions – but not WACS as considered here.
Frequency band	2.4 GHz,	Other potential systems at 5.2 GHz, 5.8 GHz and 17.1 GHz
RF Channels	Single channel	
Modulation scheme	Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS)	
Bit rate	2.4 GHz FHSS: Current systems have a rate of 1-2 Mbps 2.4 GHz DSSS: Bit rate on current systems is 2 Mbps – in future this may be increased to 11 Mbps	Other Systems: 5.2 and 5.8 GHz: Bit rates of up to 20 Mbps are expected 17.1 GHz: Bit rates of up to 150 Mbps are expected
Channel access method	CSMA-CA, TDMA	Systems complying with IEEE 802.11a (5 GHz systems) and 802.11b (2.4 GHz systems) use Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) HiperLAN systems (5 GHz systems) use Time Division Multiple Access TDMA
Frequency availability (allocation status)	Frequencies allocated worldwide and available	Frequencies at 2.4 GHz are available worldwide for use by WACS/Gatelink and do not require a licence. At 5.2 GHz, there are worldwide frequencies available which do not require a licence. At 17.1 GHz, allocation is worldwide but users require a licence for a particular geographical area.
Dependencies	None	

L.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Yes	
Message length	Not specified	Supports transfer of very large files
Transmission delay	Not known	
Availability	Not known	
Integrity	Not known	
Continuity of function	Not known	
Capacity	Not known	
Coverage (airspace category) & Range	600 m	Range is achieved at the expense of throughput. Range at 2.4 GHz: 600 m Range at 5.2 GHz: 50 m Range at 17.1 GHz: 6 m
Priority management	No	Priority could be included in future systems if required.

L.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Partially completed	Simulations have been undertaken as part of the Eurocontrol Wireless Airport Communications Systems (WACS) study
R&D Trials Pre-Operational Trials	Partially completed	Various airport site surveys have been conducted for 2.4 GHz systems either by Rockwell-Collins in Heathrow and in Palma de Majorca, and by the AEEC 763 working group in Orly.
Operational Trials	Partially completed	There are WACS/Gatelink operational trials being carried out by the following airlines: Condor, British Airways, FedEx and Swissair
Standards Development		
ICAO	No activity	No ICAO standardisation activity.
EUROCAE/RTCA	No activity	
AEEC	Initial draft available	AEEC is coordinating standards development, based on existing IEEE standards. AEEC Project Paper 763 is defining the Aircraft Network and File server supported by a WACS

Parameter	Value	Notes
ETSI	ETSI HiperLAN standard published but not specific to aviation Gatelink	ETSI has produced a European HiperLAN/1 standard, and is developing the HiperLAN/2 set of standards, some of which are finalised. ETSI BRAN HiperLAN 1 and 2 standards: HiperLAN/1 (5 GHz): ETS 300 836 ETS 300 652 HiperLAN/2 (5 GHz)
Other Standards	IEEE 802.11 (PHY & MAC layers) IEEE 802.11a (ext to 5 GHz) IEEE 802.11b (ext to 2.4 GHz)	WACS systems implemented at airports comply with the regulations applicable in the country where the airport is located **IEEE** The IEEE has produced the 802.11 set of standards for WLAN. These are finalised, but additions/updates to the standard continue to be made. Systems compliant with these standards are candidate systems for gatelink, but these standards are not generally applicable in Europe. Other bodies producing standards: IEC, ISO, Federal Communications Commission (FCC) (USA), Portable Computer and Communications Association (PCCA) (USA), Research and Development Center for Radio Communications (RCR) (Japan), Ministry of Posts and Telecommunications (MPT) (Japan), Association Francaise de Normalisation (AFNOR) (France)
Conclusion		
Equipment Development		
Prototype airborne equipment status	Available	Rockwell involved in supplying initial systems to Airbus WACS/Gatelink operational trials by airlines: CONDOR, British Airways, FedEx and Swissair
Red-label (operationally capable) airborne equipment status	Available	Equipment is advertised by Rockwell Collins
Certification	No known issues	Complicated aircraft architecture
Conclusion	Some installations	

Parameter	Value	Notes
Prototype ground equipment status	Available	
Operationally capable ground equipment status	Available	Rockwell Collins advertises its gatelink system: Integrated Information System I2S operating at 2.4 GHz, using either FHSS or DSSS conforming to IEEE 802.11
Certification	No known issues	
Conclusion	Several installations	
System Deployment		
Ground deployment plans status	Limited	Some on-going operational trials
Aircraft fleet equipment plans status	Limited	Limited deployment for operational trials
Mandatory Carriage Status	None	
Conclusion	WACS systems could be deployed today.	

L.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Aircraft architecture consists of: ▪ File server unit (FSU) ▪ Secure interface unit (SIU), ▪ Cabin Wireless LAN unit (CWLU) ▪ Microwave airborne antenna (MAA) The major issues is ensuring separation between cockpit (safety) and cabin (non-safety) services.
Ground architecture	Terminal Wireless LAN unit (CWLU)

L.4 Cost Assessment

L.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of new WACS equipment at one airport (assumes 12 ‘access points’, with three antennae per access point)	60,000	[194]
Other required equipment	n/a	
Installation	20,000	Estimate
Total initial cost per airport (single installation)	**80,000**	
Yearly maintenance costs per airport (single installation)	6,000	10% initial hardware cost
Number of airports likely to install gatelink	90	Airports with > 1 M passengers [241]
Total ground cost across all airports	**7,200,000**	

L.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of transceiver + antenna	100,000	Eurocontrol WACS Study [194]
Server interface unit, network server unit, terminal wireless LAN unit		
Integration, installation & certification		
Installation kit(s)	5,000	5% equipment cost
Service bulletin	10,000	10% equipment cost
Man-hours (80 euro/hour)	5,000	5% equipment cost
Total initial costs per aircraft (single installation)	**120,000**	
Yearly maintenance costs per aircraft (single installation)	10,000	10% initial hardware cost

L.5 Industrial Assessment

L.5.1 Stakeholder Support

Stakeholder	Comments
Airlines	CONDOR, British Airways, FedEx and Swissair are supporting trials
SITA	No known plans

L.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell have Gatelink systems under development. They have potential customers, but the choice of technology, being based on a number of off-the-shelf products, is not yet frozen. The aeronautical standards for Gatelink are not yet finalised, limiting the amount of development that is feasible.
Rockwell Collins	Rockwell Collins have their I2S Programme. The system is under development. Black label pre-production equipment has made manufactured and several demonstration programs have been supported, e.g. WACS, CAIN and others. The demonstrations comprise 2,4 Mb/s as well as 11 Mb/s (frequency hopping) technologies.

L.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	No activity
Boeing	It is understood that Boeing does not have any activity with regard to Gatelink systems.

L.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	System based on already existing COTS products System at 2.4 GHz proven to work at airports Data throughput generally sufficient Data throughput generally sufficient to meet Gatelink requirements (transfer of data during 30 minute aircraft turnaround)
Summary of Weak Characteristics	System and standards development lacking at 5.2 GHz and particularly 17.1 GHz Short range of 5.2 GHz and particularly 17.1 GHz systems
Conclusion: feasibility, maturity & timescale	Feasible within 1 year

M Next Generation Satellite System

M.1 Introduction

M.1.1 Next Generation Satellite System is a generic term referring to the potential aeronautical use of a number of emerging satellite system. This annex concentrates on the adoption of systems developed primarily for other markets. Aero-I (Annex B) and SDLS (Annex K) could also be considered as NGSS. The study has not considered other potential satellite systems such including those based regenerative payloads and Ka- and Ku-band. The emergence of such systems in the coming years is not discounted.

M.1.2 The principal NGSS are: Iridium, ICO and Globalstar. Brief descriptions of each are provided below. As ICO and Globalstar no longer have plans to provide an aeronautical service, only Iridium is considered in detail.

Iridium

M.1.3 The nominal Iridium constellation consists of 66 satellites in low earth orbit (485 miles, 780km) connected by inter-satellite links, and supported by a network of gateway earth stations. The system is designed to permit voice or data to reach its destination anywhere on Earth. The relatively short relay distance reduces the delay and enhances the quality of voice transmissions.

M.1.4 The constellation has been deployed and in operation since 1998. Each satellite covers an area 4,000 Km wide. Iridium is the only system to enable communications from one handset to another without the need to be downlinked through a gateway earth station. The satellites carry out on-board switching of the calls from the handsets.

M.1.5 A link is transferred from cell to cell and from satellite to satellite as the spacecraft orbit (approximately one earth revolution per 100 minutes). The gateways are continuously linked to at least two satellites of the constellation.

M.1.6 Iridium currently offers an aeronautical voice and data communications service.

ICO

M.1.7 The ICO constellation consists of 10 satellites in medium earth orbit. ICO offers integrated mobile satellite communications with terrestrial cellular networks through dual mode handsets.

M.1.8 The space segment configuration provides coverage of the entire surface of the earth at all times and path diversity increases the likelihood of uninterrupted calls. The orbital pattern is designed to ensure that usually two but sometimes three and up to four satellites will be in view of a user and a Satellite Access Node (SAN) at any time.

M.1.9 New ICO will also offer a family of services that are the satellite equivalent of third generation (3G) wireless services, including wireless Internet and other packet-data services. The New ICO system will route information from terrestrial networks through the ICONET and then up to the satellites for delivery to new ICO subscribers.

M.1.10 The upgrade of the New ICO network to a packet data-based system will allow to offer voice and IP-based data services to customers whose communications needs are not met by terrestrial alternatives.

M.1.11 ICO have no current plans to offer an aeronautical service.

Globalstar

M.1.12 The Globalstar system offers global, digital real time voice, data and fax via a constellation of 48 mini-satellites in low earth orbits. The system is not available above 72^{o} North or below 72^{o} South.

M.1.13 The constellation operates in a 1410 km orbit inclined at 52 degrees, and will have 8 spares. Spacecraft are operated from a San Jose Ca. control centre, and more than 60 further stations support the system as gateways. Fixed and mobile mounted terminals are supported by the system, as well as standard hand-held phones.

M.1.14 The spacecraft employ secure links to control station (C-band 6875-7055MHz), and handsets (16 cells L-band 1610-1626.5MHz up, 16 cells S-band 2483.5-2500MHz down). CDMA is employed, and data rates of up to 9600 bps are supported on terminals. Gateways cover a radius of approximately 2000km.

M.1.15 Globalstar have no current plans to offer an aeronautical service.

M.2 References

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- NGSS Capabilities, EMERTA/WP2.1.2/SOF/0.4, European Commission October 2000 [9].
- NGSS Study Synthesis Report, EMERTA/WP201/SOF/2.0, March 2001 [10].
- Iridium Aviation Datalinks for ADS", Final Report, Version 0.9, 5th July 1999. [215]

M.3 Technical Assessment (Iridium)

M.3.1 General Description

Parameter	Value	Notes
Service topology	Point to Point	Data and Voice services
ATN compliance	No	An SNDCF could be developed

Parameter	Value	Notes
Frequency band	L-band, K-band, Ka-band	User Uplink 1616 – 1626.5 MHz (L- band) User Downlink 1616 – 1626.5 MHz (L- band) Feeder Uplink 29.1 – 29.3 GHz (Ka- band) Feeder Downlink 19.4 – 19.6 GHz (K- band) Inter-satellite 23.18 – 23.38 KHz (Ka-band)
RF Channels	Four frequency sub-bands	
Modulation scheme	QPSK	
Bit rate	2400 bps	Voice and data services
Channel access method	FDMA, TDMA, TDD	
Frequency availability (allocation status)	FCC Allocation	No further action required, although frequencies are not restricted to aviation use.
Dependencies	None	

M.3.2 Performance Characteristics (Iridium)

Parameter	Value	Notes
Multiple QoS Profiles	No	
Message length	No Applicable	
Transmission delay	2 seconds	95 % See [215]
Availability	0.995	Across whole air/ground network (0.999 per hour)
Integrity	RER 10^{-6}	See [215]
Continuity of function	0.99999 per 10 min	See [215]
Capacity	236 users per beam	Each spot beam has a 700 km footprint.
Coverage (airspace category) & Range	Global	
Priority management	Yes	PPP mechanisms in avionics

M.3.3 Maturity Assessment (Iridium)

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Eurocontrol sponsored experiments	Reported in [215]
R&D Trials	DERA (UK)	DERA (UK) have flown several Iridium trials to demonstrate aeronautical performance.
Pre-Operational Trials	Not known	System is now operational
Operational Trials	Not Known	System is now operational
Standards Development		

Parameter	Value	Notes
ICAO	ICAO NGSS SARPs draft available (publication delayed)	Generic NGSS SARPS exist. Each technology will need a Technical Manual and Implementation Manual. Draft Material has been developed for Iridium, but publications has been delayed due to lack of support.
EUROCAE/RTCA	RTCA NGSS MOPS available	RTCA MOPS for avionics supporting NGSS exist, plus other relevant RTCA standards Draft NGSS SARPs exist – but introduction into Annex 10 has been delayed due to lack of acceptable service providers
AEEC	Some AEEC standards available	Some relevant AEEC standards exist
ETSI	No activity planned	
Other Standards	Yes	Iridium maintain system definition manuals
Conclusion	Immature	Although an operational system, Iridium has not completes the ICAO/EUROCAE
Equipment Development		
Prototype airborne equipment status	Available	AIRSAT-1 manufactured by Honeywell, Allied-Signal…
Red-label (operationally capable) airborne equipment status	Available	
Certification	None	FAA has awarded 9 Supplementary Type Certificates for AIRSAT-1 installations.
Conclusion	Operational System	
Prototype ground equipment status	Available	
Operationally capable ground equipment status	Available	
Certification	Available	
Conclusion	Operational System	
System Deployment		
Ground deployment plans status	Deployed	Iridium is an operational system, used for GA services in US.
Aircraft fleet equipment plans status	Limited number of GA installations	
Mandatory Carriage Status	No	No mandate is envisaged
Conclusion	Iridium is currently used for GA voice services.	

M.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	No known issues
Ground architecture	No known issues
Space Segment	Constellation consists of 66 satellites plus 6 spares in 6 planes The use of inter-satellite links enables a signal to be re-routed to another ground station if the nearest is not available, ie due to rain attenuation.

M.4 Cost Assessment

M.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of new ground station equipment for NGSS	15,000,000	Based on AMSS cost [163]
Installation	3,000,000	20% equipment cost
Total initial cost per ground station	**18,000,000**	
Yearly maintenance costs per ground station	1,500,000	10% initial hardware cost
Number of ground stations required	30	[224]
Total ground station cost	**540,000,000**	
Satellite build costs (per satellite)	25,000,000	Iridium [221]
Satellite launch cost (per satellite)	15,000,000	Iridium [222, 223]
Project management cost per satellite (100 euro/hour)	4,000,000	40,000 man hours
Total initial cost per satellite	**44,000,000**	
Number of satellites required	88	66 + 7 spare (15 launch failures) [243]
Total satellite cost	**3,872,000,000**	
Total system cost (ground stations plus satellites)	**4,412,000,000**	
Satellite plus ground system operating costs per year	84,000,000	[243]

Note: These costs are based on the Iridium system. Much lower costs would be expected for simpler constellations and in particular NGSS based on GSO.

M.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of new transceiver + antenna	29,500	Honeywell Airsat 1 (Iridium based) [220]
Integration, installation & certification		
Installation kit(s)	1,475	5% equipment cost
Service bulletin	2,950	10% equipment cost
Man-hours (80 euro/hour)	1,475	5% equipment cost
Total initial costs per aircraft (single installation)	**35,400**	
Yearly maintenance costs per aircraft (single installation)	2,950	10% initial hardware cost

M.5 Industrial Assessment

M.5.1 Stakeholder Support

Stakeholder	Comments
Iridium	Support for current voice services; continue to investigate data services.
FAA	Demonstrations of Iridium data services have been conducted.
European ANSPs	No known interest
European Airlines	No known interest

M.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	Honeywell manufacture the AIRSAT-1 Iridium-based airborne terminals. They see the system at the moment as a relatively inexpensive voice com for business aircraft, and not really for the Air Transport market.
Rockwell Collins	No current plans.
Allied Signal	Suggested retail price of the Airsat 1 is $29,500. Usage rates vary from $3.50 per minute for in-country calls to a maximum of $7 for international calls. AlliedSignal Aerospace has appointed 380 Airsat 1 dealers worldwide. (http://www.spacedaily.com/news/iridium-99e.html)
Blue Sky Network	Blue Sky Network is seeking an STC for its new airborne data and voice communications system. The La Jolla, CA-based company is using the Iridium satellite network for the BlueSkyLink C-1000, which incorporates Motorola's Iridium telephone system customized for use aboard GA and business aircraft. With cabin kits priced at $6,495, portable versions costing less than $2,000, monthly fees of $40 to $300 and $1.50 maximum per-minute usage fee, Blue Sky says the system will offer "affordable, real-time worldwide communications services to and from any aircraft."

M.5.3 Airframer/Integrator Perspective

Airframer	Comments
General	The FAA have issued 9 STCs for AIRSAT-1 installations including the following aircraft types: Raytheon 300; Bombardier CL-600; Learjet 60; Sabreliner NA-265-65; Gulfstream GV; Mystere Falcon 20; Hawker 800XP
Airbus	No plans
Boeing	Boeing have no activity with regard to NGSS systems.

M.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	World-wide point-to-point data link coverage at a reasonably high data rate, with minimal ground infrastructure.
Summary of Weak Characteristics	Delay of the generic NGSS SARPs due to the lack of suitable service providers. For an aeronautical service, each technology will need a Technical Manual and an Implementation Manual which will take some years to produce. Service likely to be expensive to operate due to satellite transmission charges. Service providers run at a high commercial risk, so that there is a higher than normal risk of service provider bankruptcy and consequent disruption to the service.
Conclusion: feasibility, maturity & timescale	A potentially capable system that suffers from the lack of a suitable service provider and the consequent delay to aeronautical standards.

N SDLS

N.1 Introduction

N.1.1 SDLS is a proposed new satellite system designed to provide safety-related aeronautical communications. The system is being developed by ESA[27] The idea is to use existing satellite and communications infrastructure as far as possible. SDLS represents a potential NGSS.

N.1.2 It should also be noted that some of the characteristics designed here are design goals and may be different in a final system.

N.1.3 The concept behind the design of the Satellite Data Link System (SDLS) is to provide improved satellite communications and surveillance services to offer:

- **Circuit Mode Voice** for AOC.
- **ATS Specific Voice Service** – replication of partyline and quasi-instant access by dedication of forward and return channels to each ATC sector.
  - All tuned receivers will constantly monitor traffic on the channel.
  - The partyline capability can be emulated by re-broadcasting the voice transmissions from aircraft via the forward channel.
- **Point-to-Point Data** – ATN Compliant sub-network.
- **Polling Service** - This 'Polling Service' allows the transfer between aircraft and ground of repetitive data and is similar to Automatic Downlinking of Aircraft Parameters (ADAP) services. It is proposed that the Polling Service be used to send:
  - Basic information - Position (latitude, longitude, altitude); Time; Figure of Merit; Flight ID.
  - Extended information - Ground Vector; Weather information; Projected profile; Short term intent; Intermediate intent.

Spectrum

N.1.4 The SDLS system could use any of the satellite bands, but the L-band seems the most probable option. Currently there is no exclusive allocation, but priority access for AMS(R)S to a 10 MHz sub-band of the MSS band is granted through a footnote in the Radio Regulations. This could require the use of priority and pre-emption rules against other MSS uses of the band.

N.1.5 Alternatively, dedicated usage of a sub-band could be decided. These issues are under consideration in ITU fora. By developing a system dedicated to AMS(R)S, the case for dedicated spectrum is likely to be easier to make and defend. The amount of spectrum needed for AMS(R)S is also under consideration, and is dependent on the range of applications to be supported, the final design of the system and the frequency re-use achievable.

[27] During the course of this study, Eurocontrol have started the process of standardising an NGSS called NexSat [266], [267] which re-uses some elements of SDLS.

System definition

N.1.6 The SDLS system is still being defined. However it is proposed that SDLS would use QPSK modulation. The data rate would be 6.8 kbits/s per channel, and the vocoder rate for voice services would be 4.8 kbits/s per channel. These baseband channels would then be mapped onto a 1 MHz Code Division Multiple Access (CDMA) channel using a spreading code.

Quality of service

N.1.7 In assessing Quality of Service required, the basic SDLS services are defined as:

SDLS 1: point-to-point ATN-compliant data services (packet mode),

- SDLS 1H services between aircraft and ATCCs with high QoS;
- SDLS 1L : services between aircraft and ALOCs with low QoS;

SDLS 2: point-to-point bi-directional voice services (circuit mode):

- SDLS 2H: services between aircraft and ATCCs with high QoS;
- SDLS 2L: services between aircraft and ALOCs with low QoS;

SDLS 3: point-to-point specific data services (packet mode);

SDLS 4: data broadcast services (packet mode) from ATCCs to aircraft.

The quality of service levels required are given in Section N.3.2.

Space Segment

N.1.8 SDLS is based on geostationary satellites in the MSS. Plans indicate that Inmarsat Space segment would be used initially with deployment of additional satellites for to meet regional demand. Spot beams would be used to supplement the global beams to meet specific regional requirements.

N.1.9 In Europe a range of spot beam services are available including the recently launched Artemis satellite.

N.1.10 The space segment also comprises the Ground Control and Monitoring function and a Satellite Control Centre function. The existing provisions for this function will be used.

Ground Earth Stations

N.1.11 The current AMSS has been designed with the Inmarsat space segment in mind, the feeder links of which are at C-Band, thus requiring rather large aperture antennas (around 12 m) at the GES. The cost of a GES is very high which tends to mean there are fewer of them, leading to a centralised system.

N.1.12 GESs used with Inmarsat satellites are normally owned by communication service providers (usually a PTT) which effectively provide the communication service to the user. In Europe, GESs which support AMSS include Goonhilly, Aussagel, and Eik. Initial deployment of SDLS would probably have to use the existing GESs when accessing the Inmarsat satellites.

N.1.13 With few GESs able to support the AMSS, this leads to reliance on a string of international networks to gain access to a GES. In the longer term wider deployment of the ATN could improve interconnectivity between States however this may take a long time in some areas of the world.

N.1.14 However when regional spot beam services are used this opens the possibility of using Ku-band feeder links. This in turn enables smaller GESs to be used (typically the size of VSAT antennas - around 2 to 3 metres in diameter) bringing the cost of the GES down in price significantly and enabling more to be deployed nearer to, or at, the end-users site. It is with this feature in mind that SDLS was conceived incorporating the requirement of operating a large number of access stations to one satellite while preserving the efficient usage of the space segment capacity.

N.1.15 The use of multiple small GESs allows a decentralised approach to the provision of satellite service. Initial design concepts have considered up to 40 small GESs distributed within the European region. This overcomes the problem of GES acting as a single point of failure for a large number of users and affects the ability of the system to meet the availability targets.

Airborne Earth Stations

N.1.16 Currently the most comprehensive AMSS installations (typified by the AERO-H system) have been designed not only to support ATSC but all other forms of communication including passenger services in an attempt to recover the costs. This has led to high costs for the multi-channel equipment, antenna and the installation. By reducing the types of communication to those related to safety and regularity of flight the AES can be made smaller, cheaper and easier to install.

N.1.17 For the Airborne Earth Stations (AESs), low cost omni-directional (isotropic) antennas could be used with low power transmitters (around 30W has been estimated) which do not require forced air-cooling. The resulting reduced equipment size and cost makes it more attractive for smaller aircraft to be equipped and possibly even low-end GA. It is anticipated that the Power Amplifier (PA) unit would be able to be installed close to the antenna to minimise cable losses. The Satellite Data Unit (SDU) unit would be mounted in the normal avionic racks.

N.1.18 The low size and cost of the avionics would make it feasible to have dual installations to achieve the level of redundancy to meet high levels of availability for safety related communications.

N.1.19 The SDU would be connected to the audio distribution system and to a CMU for data link messaging similar to other data systems such VDL2. The Polling Service contained in the SDU would require access to data sources from the aircraft data buses (e.g. ARINC 429) to obtain positional and other ADAP information.

Standards

N.1.20 As the new satellite service will support civil aviation world-wide, ICAO SARPS will need to be developed. It is anticipated that much of the existing AMSS SARPS could be updated to include SDLS features.

N.1.21 In addition, MASPS and MOPS will need to be developed. A further step will require standardisation in the avionics industry on equipment form, fit and function characteristics; this is traditionally the role of the AEEC.

N.1.22 The GES operators will need a more detailed set of technical standards than is provided in the ICAO SARPS. For the current AMSS this level of detail was contained in the Inmarsat System Definition Manual (SDM). The SDM is used by GES and avionics manufacturers to produce equipment. This same level of detail will be required with SDLS.

Demonstration

N.1.23 The SDLS concept has evolved over a number of years. ESA is funding the development of a set of representative elements of the SDLS which includes:

- Two Ku band Ground Earth Stations initially based in Toulouse and Rome using the EMS satellite which is no longer active. The Artemis regional satellites is available for future trials;
- Two Aeronautical Earth Stations supporting the point-to-point data communications, a polling service for aircraft position reporting, a voice party-line and point-to-point voice capability;
- In addition several ATS control positions are being developed to demonstrate the key features of SDLS to the aeronautical community.

N.1.24 Trials are planned for the second half of 2002 during which the performance of the key features will be demonstrated and evaluated.

N.2 References

N.2.1 The following references were used in the development of this Annex:

- Satellite Data Link System (SDLS), Claude Loisy ESA, 30 January 2002 [44].
- Satellite Data Link System (SDLS) Satellite Data Link System (SDLS), Present Status and Projected Future Activities, Claude Loisy, ESA, October 2001 [201].
- Preliminary Study of Satellite Spectrum Requirements - Review and Update of ESA SDLS and IATA studies, Eurocontrol COM-SAT-REQ-D1, Edition 1.1, April 2002 [195].
- Satellite Data Link System (SDLS) - A Dedicated Mobile Satellite Communication System Responding to the Highly Demanding Requirements of Civil Aviation, Claude Loisy, ESTEC, ESA [199].
- Most Probable Satellite Communication Operating Concept for ECAC and other regions of the world, Eurocontrol, Draft edition, May 2002 [200].

N.3 Technical Assessment

N.3.1 General Description

Parameter	Value	Notes

Parameter	Value	Notes
Service topology	Uplink point-to-point, Downlink point-to-point	
ATN compliance	Yes	Additional specific service also provided.
Frequency band	Satellite bands (L-band, C-band, Ku-band)	1545-1555 MHz for the downlink (from satellite to AES) 1646.5-1656.5 MHz for the uplink (from AES to satellite)
RF Channels	867 KHz bandwidth	
Modulation scheme	QPSK	Ground to air: Synchronous CDMA QPSK Air to ground: Quasi Synchronous CDMA QPSK
Bit rate	6.8 Kb/s (4.8 Kb/s vocoder) per channel	SDLS proposes to use a coding scheme using a convolution code (rate 3/4 and K=5) and, with a vocoder rate of 4.8 Kbps rate (6.4 Kbps with error protection) leads to a link rate of 6.8 Kbps including synchronisation overhead.
Channel access method	CDMA	Forward channels are operated as slotted CDMA by each GES sending information requests to the controlled AES. A forward channel is allocated to one GES; this GES sends the information on a slotted burst, which is received by all AESs. Only the addressed AES recovers and processes the message. Return channels are operated either: • Asynchronously: For the Polling Service (PS) services, a set of AESs share a CDMA coded channel for the return link in a slotted reservation scheme. Each AES has access to the return channel in a predefined slot burst or frame according to the message length which is indicated by the GES in the signalling information carried in the forward link. For other services, a set of AESs uses the same CDMA channel using slotted aloha. • Synchronously: A TDMA CDMA channel is used.
Frequency availability (allocation status)	Yes	Access to L-band spectrum for AMS(R)S is guaranteed under a Radio Regulation Footnote. The possibility of sharing arrangements within the MSS is still under discussion in ITU. Hence frequencies are available but would need to be shared by other uses ie existing Inmarsat AMSS
Dependencies	None known	

N.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Not Defined	
Message length	Not defined	SDLS has been designed with specific Automatic Position Reporting (APR) protocols to efficiently handle frequent short messages such as ADS-type, ADAP or position reporting messages.
Transmission delay	SDLS 1H – 8 secs SDLS 1L – 30 secs SDLS 2H – NA SDLS 2L – NA SDLS 3 – 8 secs SDLS 4 – No info	See Section N.1.6 for definitions of the different SDLS service levels.
Availability	SDLS 1H – 99.96 % SDLS 1L – 99.795% SDLS 2H – 99.96% SDLS 2L – 99.795% SDLS 3 – 99.96% SDLS 4 – No info	See Section N.1.6 for definitions of the different SDLS service levels.
Integrity	SDLS 1H – 10^{-7} SDLS 1L – 10^{-6} SDLS 2H – 10^{-7} SDLS 2L – 10^{-6} SDLS 3 – 10^{-6} SDLS 4 – No info	See Section N.1.6 for definitions of the different SDLS service levels.
Continuity of function	SDLS 1H – 99.96 % SDLS 1L – 99.795% SDLS 2H – 99.96% SDLS 2L – 99.795% SDLS 3 – 99.96% SDLS 4 – No info	See Section N.1.6 for definitions of the different SDLS service levels.
Capacity	Design Issue	
Coverage (airspace category) & Range	Global coverage capability: In remote areas and over water and Gap-free coverage down to ground altitude.	
Priority management	Not defined	

N.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status R&D Trials	Partially completed	ESA and Eurocontrol are co-operating on a series of projects including the development of test bed and flight trials. The SDLS concept has evolved over a number of years. ESA is funding the development of a set of representative elements of the SDLS which includes – 2 Ku band Ground Earth Stations initially based in Toulouse and Rome using the EMS and Artemis regional satellites. 2 Aeronautical Earth Stations supporting the point-to-point data communications, a polling service for aircraft position reporting, a voice party-line and point-to-point voice capability. In addition several ATS control positions are being developed to demonstrate the key features of SDLS to the aeronautical community. Trials are planned for the second half of 2002 during which the performance of the key features will be demonstrated and evaluated.
Pre-Operational Trials	No activity	
Operational Trials	No activity	
Standards Development		
ICAO	New Activity	ICAO activity - The recent meeting of AMCP/8 has agreed to restart activity on NGSS including SDLS/NexSAT systems.
EUROCAE/RTCA	No activity	Reuse of AMSS and NGSS standards possible
AEEC	No activity	Reuse of AMSS and NGSS standards possible.
ETSI	No activity	An ETSI EN for the AES and possibly GES would be required.
Other Standards	ESA Development Standards	Full standards will be required by GES and AES Developers.
Conclusion		
Equipment Development		
Prototype airborne equipment status	Available	Alcatel Space is developing a mobile communications system demonstrator
Red-label (operationally capable) airborne equipment status	None	System is not mature enough for industrial development.

Parameter	Value	Notes
Certification	No activity	
Conclusion	R&D Only	Early prototypes are being developed,
Prototype ground equipment status	Available	Prototype GES are being developed under contract to ESA
Operationally capable ground equipment status	None	
Certification	No activity	
Conclusion	R&D Only	Early prototypes are being developed
System Deployment		
Ground deployment plans status	None	
Aircraft fleet equipment plans status	None	
Mandatory Carriage Status	None	
Conclusion	No deployment plans	

N.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Too early for analysis, however similarity with AMSS indicates that significant issues are not anticipated.
Ground architecture	Potential issue is frequency re-use management where local GES are deployed and sharing of AMS(R)S with existing users.

N.4 Cost Assessment

N.4.1 Ground Costs

Specific equipment and operations	Value (euro)	Notes
Cost of small ground earth station (GES)	1,000,000	Estimate
Installation	200,000	20% equipment cost
Total initial cost per ground station	**1,200,000**	
Yearly maintenance costs per ground station	100,000	10% initial hardware cost
Number of ground stations (small GESs) required	40	[200]
Total ground station cost	**48,000,000**	
Satellite build costs (per satellite)	140,000,000	Geo-stationary (same cost as for Inmarsat-4)
Satellite launch cost (per satellite)	70,000,000	
Project management cost per satellite (100 euro/hour)	10,000,000	50,000 man hours
Total initial cost per satellite	**220,000,000**	
Number of satellites required	2	1 in orbit plus 1 spare [200]
Total satellite cost	**440,000,000**	
Total system cost (satellites plus ground stations)	**488,000,000**	

Note: Under the SDLS concept there is no intention to launch satellites but it will reuse existing space segment e.g. Inmarsat or regional systems. Therefore it is not correct to include these costs. They are however stated to indicate the relative cost of satellite systems of this nature.

N.4.2 Airborne Costs

Specific equipment and operations	Value for AT digital (euro)	Notes
Hardware		
Cost of new satellite system avionics	179,392	Based on AMSS cost of Rockwell Collins AERO-I system (3 channel) SAT-2000-3 [218]
Integration, installation & certification		
Installation kit(s)	8,970	5% equipment cost
Service bulletin	17,939	10% equipment cost
Man-hours (80 euro/hour)	8,970	5% equipment cost
Total initial costs per aircraft (1 transceiver)	**215,270**	
Yearly maintenance costs per aircraft (1 transceiver)	17,939	10% initial hardware cost

Note: The costs included are based on Aero-I avionics. Feedback following the Second Stakeholder workshop indicated that the design goal of SDLS avionics would be closer to Aero-L system (circa €50,000)

N.5 Industrial Assessment

N.5.1 Stakeholder Support

Stakeholder	Comments
ESA	Support development of SDLS
Eurocontrol	Eurocontrol have started a new NGSS programme called NexSat which reuses several elements of the SDLS programme and the SDLS demonstrator.

N.5.2 Vendor Perspective

Manufacturer	Comments
Alcatel	Manufacturer of prototype equipment
Rockwell Collins	Rockwell Collins have no activity in this area.
Honeywell	Honeywell has no activity in this area.

N.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	No Plans
Boeing	Boeing have no activity in relation to the SDLS system.

N.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	SDLS support voice and data communications Re-use of L-band frequencies will support safety of life service Offers potential for lower cost satellite system
Summary of Weak Characteristics	Does not utilise modern space segment engineering such as regenerative payloads. The current definition of the polling service is not aligned with other ADD developments but further refinement is expected.
Conclusion: feasibility, maturity & timescale	SDLS could be in service by 2010 Greater use could be made of the L-band frequencies.

O 3G/UMTS/CDMA

O.1 Introduction

O.1.1 Third Generation Mobile Communications (3G) has been developed by the telecommunications industry to support broadband personal mobile communications. 3G uses the Universal Mobile Telecommunications System (UMTS) protocols and Code Division Multiple Access (CDMA). Within 3G there are two proposed systems – WCDMA and CDMA2000.

O.1.2 Eurocontrol are actively developing the aviation use of 3G systems. This work has included simulations, bench tests and successful flight trials. The information in this annex is drawn from conversations with Eurocontrol staff and Eurocontrol reports.

O.1.3 The availability of the high bandwidth enables a variety of content to be transmitted, including voice, multimedia, internet and other sources of data. Additionally, 3G systems are intended to be highly compatible, offering services such as worldwide roaming.

O.1.4 3G is an exciting technology which has the potential for offering a terrestrial broadband solution to aviation users, with the cost advantage of VHF solutions, and the bandwidth of satcom solutions.

O.1.5 There are good reasons for adopting 3G/CDMA for aviation use:

- It can provide a high-throughput data, voice, and video communication link available over continental airspace;
- It has the potential of supporting a wide range of services including ATS, AOC, AAC and APC;
- It will be compatible with the future satellite services, so that a seamless 3G service over continental and oceanic airspace will be possible;
- The 3G technology is already developed and standardised and available in a mass market – therefore aviation standardisation should be very rapid, and system component costs will be low and experienced engineers widely available.

System operation

O.1.6 There are different frequency bands in which the system could operate – the VHF (aeronautical band), 2 GHz, and 5 GHz are currently all being considered. The 2 GHz band has not yet been used in the prototype equipment.

O.1.7 The throughput achieved to-date at 5 GHz with 5 MHz bandwidth is 1.5 Mbits per second. The system can accommodate both ATN and IP. Transmission delay is in the region of a few milliseconds.

O.1.8 Eurocontrol has simulated and performed flight trials with the Time Division Duplex (TDD) system. With the TDD system, the range is about 25 km. If using TDD, the system is limited to a range of 25 km at the nominal throughput - greater range is possible but only at the expense of throughput.

O.1.9 Simulation and bench tests have been done for Frequency Division Duplex (FDD), with trials planned in the near future. With FDD, using either WCDMA or CDMA2000, range is only power limited, and so the range can be of the order of 100-200 km. The size of a cell is therefore not an issue for FDD.

Standardisation

O.1.10 A large part of the aeronautical standards that will be required for the 3D/CDMA system can simply be carried over from the current 3G standards. However, the aeronautical 3D/CDMA standards will need to differ from the current 3G standards due to the different part of the spectrum being used, with consequent impact on the RF equipment.

O.1.11 The aeronautical system has to accommodate a higher Doppler shift than the current 3G standards. This has to be compensated for in the system and will impact on the standard.

O.1.12 ICAO has not yet been approached to produce ICAO SARPs. Also no EUROCAE/RTCA MOPS activity is yet being considered.

Interest and support

O.1.13 Discussions with the US (including the FAA) are ongoing to maintain interest. Airlines are also showing interest in the system. Roke Manor Research, a division of Siemens, produced the prototype ground equipment used in the demonstrator trials.

O.1.14 The simulation work has been done by Agilent Technologies (formerly Sirius Communications). Avionics manufacturers such as Rockwell Collins are becoming aware of the system. The states are being made aware of the system through the Eurocontrol process of frequent reporting to states.

Spectrum

O.1.15 Text is currently being considered for an agenda item in WRC 2003 or 2006 for consideration of a spectrum allocation for the system. However the system is expected to be able to co-exist with MLS in the MLS band with no problems. The system may also use the RadioLAN band.

Equipment costs

O.1.16 The equipment in use is currently prototype. No work has yet been done on target costs for avionics or ground equipment. The market for the system is expected to be large, and since production runs should be large, the system component costs should be low.

Demonstrator trials

O.1.17 The aeronautical 3G/CDMA system supports any application in principle. A demonstrator has been flown involving QinetiQ's BAC1-11 research aircraft, showing the ability to simultaneously transfer voice, pictures, video, and internet data in both directions between the aircraft and the ground.

O.1.18 The demonstrator flights showed that previously predicted performances could be obtained. More trials are planned for different configurations.

Timescales

O.1.19 Technically there is not much remaining to be done to bring the system up to the point where it could be used operationally. It could be developed quickly if required to provide non-ATC aeronautical services by 2006.

O.1.20 More evidence of system performance would be required for ATC applications, so that for ATC the system could be operational around 2012 to 2015.

System capability

O.1.21 There would be no problem for the system to cover all four services: AAC, APC, AOC, and ATC. The system can support different levels of priority. The system is predominantly terrestrial, but would be compatible with the planned Inmarsat-4 satellites which will operate using the 3G system. Therefore a seamless terrestrial-satellite service over continental and oceanic regions is possible.

O.1.22 The system may operate in a similar way to the concept for a software radio. If so, it will be able to support other systems with their own protocols, such as VDLs 2, 3, and 4, or other wideband systems. Work on software radios is being progressed within the Communication Unit at Eurocontrol.

O.2 References

O.2.1 The following references are relevant to this system:

- Second Airborne Trials with the Siemens 3G Testbed, Eurocontrol, September 2002 [211].
- Study into Modifying the Siemens 3G Testbed for Airborne Trials, Eurocontrol, August 2002 [212].
- 3rd Generation Partnership Project (3GPP) Standards, 3GPP [213].
- WCDMA Gets Set For TakeOff in Air Transport, 3G Newsroom, 15th March 2002 [214].

O.3 Technical Assessment

O.3.1 General Description

Parameter	Value	Notes
Service topology	Uplink point-to-point, Downlink point-to-point	
ATN compliance	Yes	The system can be ATN compliant and/or IP compliant.
Frequency band	5 GHz (C-band)	Could also operate in the 2 GHz and/or VHF aeronautical band
RF Channels	Single 5 MHz channel	
Modulation scheme	QPSK	
Bit rate	1.5 Mbps	

Parameter	Value	Notes
Channel access method	CDMA	With Frequency Division Duplex (FDD) or Time Division Duplex (TDD) for duplex transmission
Frequency availability (allocation status)	Frequencies not yet assigned	Text is currently being considered for an agenda item in WRC 2003 or 2006 for consideration of a spectrum allocation for the system. However the system is expected to be able to co-exist with MLS in the MLS band with no problems. The system may also use the RadioLAN band.
Dependencies		
Conclusions		
Summary of Strong Characteristics	Highly capable system Support for high bandwidth applications Interoperability with future satellite systems Potential cost savings due to mass market link	
Summary of Weak Characteristics	Certification issues over shared use of spectrum.	
Conclusion: feasibility, maturity & timescale	Retained in the roadmap as a potential system for 2012-15 Recommendations for EC funding of research? Non-safety-critical services possible (AAC/APC) by 2006 Safety and regularity of flight services (ATC/AOC) by 2010	

O.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles		
Message length	Not applicable	
Transmission delay	< 10 ms	
Availability	Design issue	
Integrity	Design issue	
Continuity of function	Design issue	
Capacity		
Coverage (airspace category) & Range	Range of 200 km with FDD	Range with TDD limited to ~25 km
Priority management	Yes	Designed to support multi-media applications. Priority, precedence and pre-emption services are contained in the commercial standards.

O.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	On-going	Eurocontrol are conducting simulations and bench tests. Simulation work performed by Agilent Technologies.
R&D Trials	On-going	Eurocontrol are conducting a series of flight trials at VHF, 2GHz and 5GHz. Flight trial results are consistent with simulation results and indicate a high level of performance. A demonstrator has been flown involving QinetiQ's BAC1-11 research aircraft, showing the ability to simultaneously transfer voice, pictures, video, and internet data in both directions between the aircraft and the ground. The demonstrator flights showed that previously predicted performances could be obtained. More trials are planned for different configurations.
Pre-Operational Trials	No activity	System is still at the prototype stage
Operational Trials	No activity	
Standards development		
ICAO	No activity	No aviation standards activity has been instigated. ETSI has developed non-aviation 3G standards and is part of 3GPP which develops 3G standards.
EUROCAE/RTCA	No activity	
AEEC	No activity	
ETSI	No activity	
Other Standards	Yes	3G is supported by a full set of open standards developed by 3GPP
Conclusion	No aviation standards activity	3G has the potential for standardisation much quicker than normal aviation technologies due to the maturity of the commercial standards.
Equipment Development		
Prototype airborne equipment status	Available	Eurocontrol trial equipment built by Roke Manor Research (Siemens).
Red-label (operationally capable) airborne equipment status	No activity	
Certification issues	No activity	
Prototype ground equipment status	Available	Eurocontrol trial equipment built by Roke Manor Research (Siemens).
Operationally capable ground equipment status	No activity	
Certification Issues	No activity	

System Deployment		
Ground deployment plans status	No activity	
Aircraft fleet equipment plans status	No activity	
Mandatory Carriage Status	No mandate foreseen	
Conclusion	Technically there is not much remaining to be done to bring the system up to the point where it could be used operationally. It could be developed quickly, if required, to provide non-ATC aeronautical services by 2006. More evidence of system performance would be required for ATC applications, so that for ATC the system could be operational around 2012 to 2015.	

O.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	No activity
Ground architecture	No activity

O.4 Cost Assessment

O.4.1 No work has yet been done on target costs for avionics or ground equipment. The market for the system is expected to be large, and since production runs should be large, the system component costs should be low.

O.5 Industrial Assessment

O.5.1 Stakeholder Support

Stakeholder	Comments
Eurocontrol	Eurocontrol are actively researching the potential of 3G
FAA	FAA support Eurocontrol activities.

O.5.2 Vendor Perspective

Manufacturer	Comments
Honeywell	No activity
Rockwell Collins	No activity

O.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	No activity
Boeing	Boeing have no activity in relation to the 3G/CDMA system.
Honeywell	Honeywell has no activity in this area.

O.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Highly capable system Support for high bandwidth applications Interoperability with future satellite systems Potential cost savings due to mass market link
Summary of Weak Characteristics	Certification issues over shared use of spectrum.
Conclusion: feasibility, maturity & timescale	Retained in the roadmap as a potential system for 2015+ Recommendations for EC funding of research? Non-safety-critical services possible (AAC/APC) by 2006 Safety and regularity of flight services (ATC/AOC) by 2010

P Boeing Connexion System

P.1 Introduction

P.1.1 The Boeing Connexion system is a satellite-based data communication system that will provide broadband data services such as internet, TV, and radio to aircraft using leased Ku-band satellite transponders. The system will operate in the 14.0-14.5 GHz band for aircraft-to-space links and in portions of the 11.2-12.75 GHz band (depending on region) for space-to-aircraft links.

P.1.2 The system will offer uplink rates of up to 10 Mbps per aircraft, and downlink data rates of up to 1.5 Mbps. Thus the system is highly asymmetrical, the uplink offering a far higher throughput than the downlink. Airplane passengers will access the system using a laptop computer, PDA or seatback terminal.

P.1.3 Boeing has total control over the system. The system gained FAA certification in May 2002, and certification for use in UK airspace in July 2002.

P.1.4 It may be difficult to modify the Boeing system to provide ATS services, with the required guarantees of reliability, availability, safety, and security. (For this reason, the study team were unsure whether it was appropriate to keep the description of the system in the Annex - however it has been retained as it is still a datalink system of interest.)

System description

P.1.5 The proposed system is composed of four segments:

- a **space segment** which consists of leased FSS transponders
- an **airborne terminal segment** that consists of satellite terminals installed on multiple aircraft
- a **ground earth station segment** which consists of one or more FSS Earth stations
- a **Network Operations Center (NOC) segment** that controls the aggregate emissions of the system in order to prevent interference to other co-frequency systems.

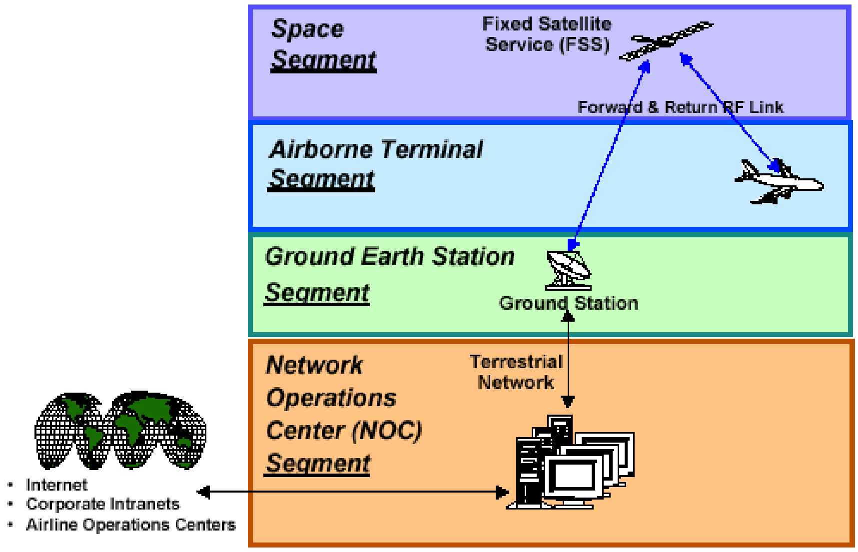

Figure P-1: Boeing Connexion system segments (figure from [209])

P.1.6 The ground earth station segment is connected to the NOC segment with redundant high-speed data connections. Multiple ground earth stations and NOCs may be included in the system for redundancy.

Uplink

P.1.7 The connection from the ground up to the satellite will employ up to four transponders (carriers), with uplink data rates of between 5 and 10 Mbps per transponder. The system uses a direct sequence spread spectrum (DSSS) waveform to minimize interference.

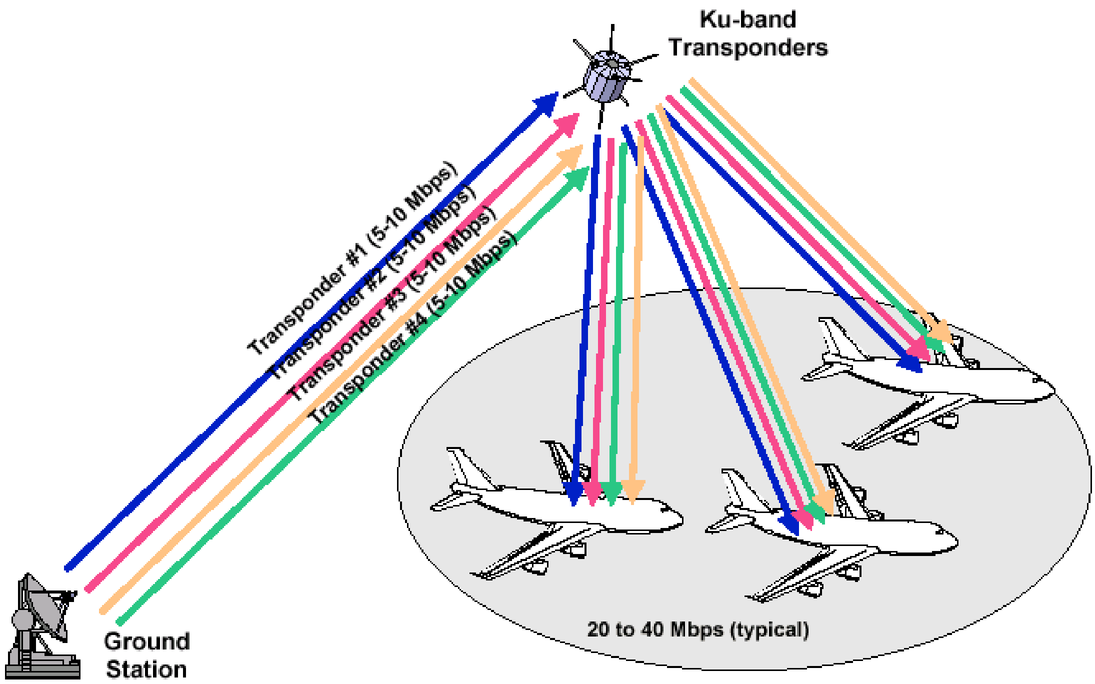

Figure P-2: Data uplink via transponders (carriers) in Boeing Connexion system (figure from [209])

P.1.8 Each aircraft will be capable of receiving four transponders from the satellite for a total data rate of between 20 and 40 Mbps. Each forward link signal transmitted to the aircraft carries an IP packet stream of video and data content.

P.1.9 Packets are unicast, multicast or broadcast to aircraft in the transponder coverage region. An onboard router accepts only those packets addressed to that aircraft and routes the packets to passengers via the onboard LAN.

P.1.10 Live TV content and pushed web page content (most popular web pages) are multicast to aircraft. The web content is cached in an onboard server for rapid availability to passengers.

P.1.11 The satellite links will only be used to convey content that is not available from the onboard server. All e-mail will be received and transmitted in real-time over the satellite links.

Downlink

P.1.12 As on the uplink, the system uses a direct sequence spread spectrum (DSSS). The system downlink uses demand assigned multiple access (DAMA) to adjust the transmit data rate from the aircraft (16 Kbps to 1.5 Mbps) to match the aircraft demand.

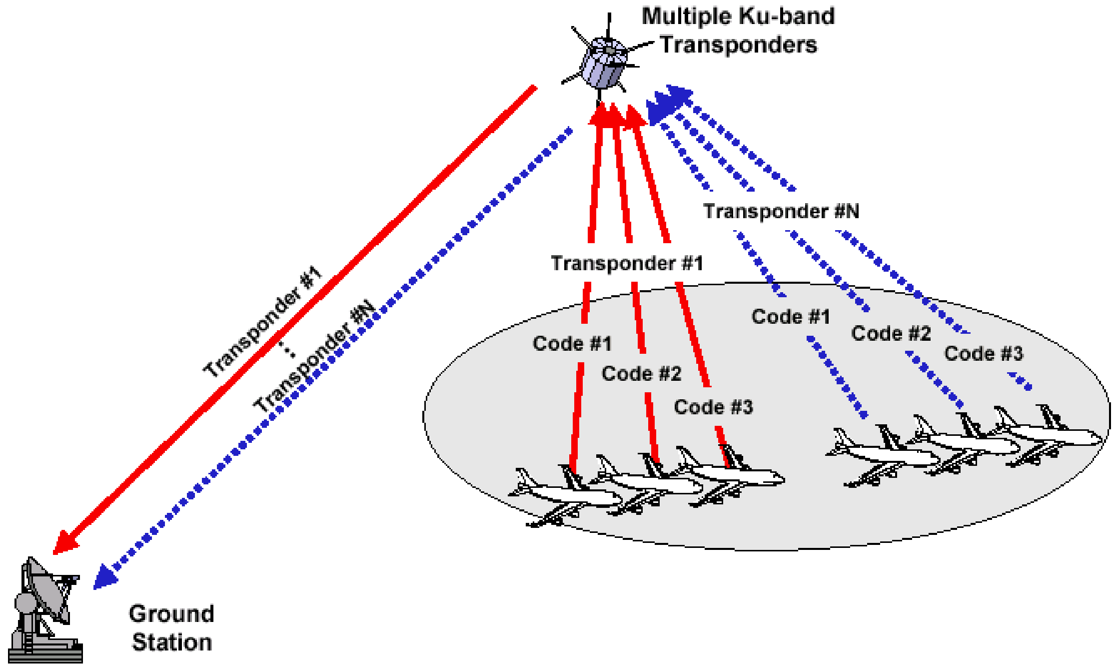

Figure P-3: Data downlink via transponders (carriers) in Boeing Connexion system (figure from [209])

P.1.13 The number of DSSS chips per bit is adjusted to maintain a nearly constant chipping rate of 90% of the transponder bandwidth. Multiple aircraft simultaneously access each return link transponder using different pseudo noise (PN) code phases (similar to CDMA). The system experiences some loss of performance (about 1 dB) due to self-interference from asynchronous aircraft transmissions.

Airborne antenna design

P.1.14 Boeing will initially offer airlines an electronically scanned phased array antenna that mounts flat on the crown of the aircraft. The antennas cause some additional aerodynamic drag to the aircraft.

P.1.15 The antennas will be mounted on top of the aircraft fuselage and separated from each other by approximately 1.25 meters to prevent self-interference. Prototype transmit antennas are currently being fabricated by Boeing, and receive antennas have been flight tested for a number of years.

P.1.16 Both phased array antennas can be electronically scanned to about 70 °. This scan angle performance is sufficient for initial operation but is inadequate for busy higher latitude air routes in North America, Europe and the North Atlantic.

P.1.17 A different antenna design that can scan down to the horizon is required for operation at latitudes above 60°. Such antennas typically protrude more above the top of the aircraft and incur additional aerodynamic drag. Boeing is working with suppliers to develop high performance antennas that can scan down to the horizon.

Deployment

P.1.18 The system will use leased Ku-band transponders on geostationary satellites to provide an initial service. Boeing plans to grow the system capacity with customer demand by leasing additional transponders.

P.1.19 Existing Ku-band satellites can provide coverage over most continental landmasses. However, transponder coverage is currently not available over popular trans-oceanic air routes. Boeing plans to provide a North Atlantic air route service using transponders that were recently added as a “piggy-back payload” to an in-production commercial satellite.

P.1.20 A CONUS service is planned for late 2001, with expansion to the Atlantic & Pacific Oceans, Europe, Canada and South/Central America in 2003. A service to Asia and Africa is planned for 2004.

P.2 References

- Connexion by Boeing - Broadband Satellite Services for Aircraft, Michael de La Chapelle et al., Boeing Space & Communications, July 2001 [209].
- Connexion by Boeing - Broadband Satellite Services for Aircraft, AEEC Data Link Users Forum, Boston, USA, July 2001, Al Burgemeister, The Boeing Company [210].
- Boeing's inflight Internet service gets FAA certification, Puget Sound Business Journal, May 2002 [253]
- United Kingdom Grants License for Connexion by Boeing, CNN Money, July 2002 [254].

P.3 Technical Assessment

P.3.1 General Description

Parameter	Value	Notes
Service topology	Point-to-point	The major aim of the system is to provide video (television) and high bit rate transmission (web access using cache mechanism on board aircraft) from ground to air in a multicast or broadcast mode. To a lower extent the system could also support point-to-point communication.
ATN compliance	No	The basic packet standard is IP compliant. It is not a basic service but an ATN packet could be embedded in an IP packet.
Frequency band	Service Link: Satellite to AES: 11.2-12.75 GHz AES to Satellite: 14.0-14.5 GHz Feeder Link: Satellite to GES: 19.3-19.7 GHz GES to Satellite: 29.1-29.5 GHz	Ku band used also by VSAT. Exact allocation depends on the ITU region considered.
RF Channels		
Modulation scheme	Direct Sequence Spread Spectrum (DSSS)	
Bit rate	5-10 Mbps uplink 16 kbps – 1.5 Mbps downlink	
Channel access method		
Frequency availability (allocation status)	Frequency usage currently granted in US, Canada, UK, & Germany.	Frequency usage needs to be granted by the country where the service is intended to be operated.
Dependencies	Availability of Ku transponders on board satellite.	The service is totally under the control of Boeing

P.3.2 Performance Characteristics

Parameter	Value	Notes
Multiple QoS Profiles	Not yet clearly defined	The intention of the system is to support services to the passenger that are not safety critical, so the QoS mechanisms are mainly defined to offer the maximum flexibility to the passenger, not necessarily the highest QoS.
Message length		
Transmission delay	Earth station to satellite ~125 ms	Signal transmission delay.
Availability		
Integrity		
Continuity of function		
Capacity	Receive: 20 to 40 Mbps Send: 16 kbps to 1.5 Mbps	Link data rates of 5 to 10 Mbps per satellite transponder for the uplink direction. Each aircraft could receive up to four transponders (20 to 40 Mbps). Link data rate of 16 kbps to 1.5 Mbps per aircraft based on a CDMA-like technique (each transponder is managing a number of CDMA like codes).
Coverage (airspace category) & Range	Global coverage as soon as satellites and Ku transponders are available.	
Priority management	Unknown	The nature of the services does not justify the implementation of such mechanism.

P.3.3 Maturity Assessment

Parameter	Value	Notes
System Development		
R&D, modelling & simulations programme status	Unknown	Initial services are already offered to a limited number of customers (Direct TV and web access for email). On the airline side the implementation of the system on board seems to be very confidential up to now. No claim from Boeing to offer ATM related services with Connexion due to the fact that Boeing takes an initiative to develop progressively an ATM services offer in which satellite technology will certainly take a significant place (the Work together initiative)
R&D Trials	Unknown	
Pre-Operational Trials	Unknown	
Operational Trials	Unknown	
Standards Development		
ICAO	No Activity	
EUROCAE/RTCA	No Activity	
AEEC	No Activity	
ETSI	No Activity	
Other Standards	No Activity	
Conclusion	No Activity	It is not sure that Boeing is pushing to the development of standards in order to keep the total control of the service provision
Equipment Development		
Prototype airborne equipment status	Prototypes exist and are currently tested.	
Red-label (operationally capable) airborne equipment status	Unknown	
Certification	No known issues	The FAA granted certification for the airborne equipment on 7th May 2002.
Conclusion	Equipment certified	
Prototype ground equipment status	Unknown	
Operationally capable ground equipment status	No	CONUS services already available with a limited number of users.
Certification	Unknown	
Conclusion	Operational system	
System Deployment		
Ground deployment plans status		Boeing intends to use the ground equipment of existing satellite service provider (AT&T for instance).

Parameter	Value	Notes
Aircraft fleet equipment plans status		A number of airlines have signed agreements with Boeing: Lufthansa, Japan Airlines, British Airways.
Mandatory Carriage Status	No plans	A mandate is not envisaged
Conclusion	No ATS role	

P.3.4 Complexity Assessment

Parameter	Issues
Airborne architecture	Requires the installation of Boeing equipment.
Ground architecture	The service relies on a ground satellite and internet service provider: e.g. AT&T has been selected to provide the service above US

P.4 Cost Assessment

P.4.1 Cost figures are not available for Boeing Connexion.

P.5 Industrial Assessment

P.5.1 Stakeholder Support

Stakeholder	Comments
Lufthansa	Lufthansa has teamed up with Boeing for three-month trials of the Connexion system starting in March 2003. The demonstrations will involve trans-Atlantic flights between Europe and the United States.
British Airways	British Airways have announced plans for a three-month trial of the Boeing Connexion system. The British Airways service demonstration will begin in February 2003.
Japan Airlines	Japan Airlines has announced it has signed a Letter of Intent to equip 10 of its long-range jetliners with Boeing Connexion on routes between Asia and Europe

P.5.2 Vendor Perspective

Manufacturer	Comments
Rockwell Collins	Collins is actively participating in broadband satellite technology development together with partner companies. The technology will be made available to airline operators consistent with the available service level, to preclude airborne system functions and cost without the corresponding service and infrastructure provisions.
Honeywell	No activity.

P.5.3 Airframer/Integrator Perspective

Airframer	Comments
Airbus	No activity
Boeing	The system is entirely controlled by Boeing. It is not, however, limited to Boeing aircraft – an Airbus business jet has been fitted with the technology. Boeing intends to use the ground equipment of existing satellite service providers (AT&T for instance). Initial services are already offered to a limited number of customers (Direct TV and web access for email). The implementation of the system on-board has been very confidential up to now. No claim from Boeing to offer ATM-related services with Boeing Connexion.

P.6 Conclusions

Parameter	Conclusion
Summary of Strong Characteristics	Throughput and coverage. System close to operation, with expected significant take-up for IFE. Some potential to be used for non-safety critical ATM communication services with the benefit to capitalise on the investment made for IFE.
Summary of Weak Characteristics	Not compliant with ICAO SARPs. Does not operate into the AMSS frequency band. Still under testing and requires frequency licence authorisation. Dedicated to internet applications onboard aircraft. Cost of avionics is high. No plans revealed on the use of the system to support ATM safety-related communication services. The system is not designed for ATM communications.
Conclusion: feasibility, maturity & timescale	Should be operational by 2003. Service available for passenger communications but no service usable for ATM purpose yet defined and planned.