DFS Deutsche Flugsicherung

DART

Comparative Data Link Investigations

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Preface

The present report was compiled by DFS Deutsche Flugsicherung GmbH within the scope of the project “Demonstrator and ATN Research Test Bed” (DART).

The DART project, which is co-sponsored by the CEC within the framework of the project “ATN trials infrastructure” (ATIF), was started by DFS in 1995 with the aim of playing an active role in the international ATN standardisation and SARPs validation process, and of providing an ATN evaluation platform within an European evaluation environment. Furthermore, this test bed has been intensively used for various evaluation activities of future ATM technologies and ATM procedures based on ATN or different mobile data links.

The comparative data link investigations described in this document were performed with the intention of providing assistance in the choice of future mobile data links to be used for Airline Operational Communication (AOC) and Air Traffic Service Communication (ATSC).

Due to its global importance, the decision-making process regarding the use of mobile data links will take place in close co-operation with our partners and customers. Consequently, this report has been compiled in the English language to enable as many partners as possible to share the results.

0 Management Summary

0.1 General

An improvement of present air navigation systems and procedures to fulfil the increasing capacity demand is an enormous challenge for all those involved.

With the adoption of the DFS data link strategy which is part of the organisation's strategy development process, an important decision was made to be prepared for this challenge. This data link strategy plans the introduction of the Aeronautical Telecommunication Network (ATN) (in a first step for air/ground communication), data link technologies, data link services and Air Traffic Management (ATM) procedures founded on them as soon as possible, reasonable and justifiable.

This comparative data link investigations, by which three data links ("Aeronautical Mobile Satellite Service" (AMSS), "Mode Select" (Mode S) and the "North European ADS-B Network" (NEAN)) were assessed, supplied an important basis for the decision making process towards their possible use. By this approach the process of selecting suitable air/ground data link technologies and their prospective operational use could be progressed.

Ongoing activities around the introduction of data link into the ATM environment (EU-projects, Eurocontrol projects, national planning) are centred around the use of VDL Mode 2 systems. For this reason, it may be questioned why no VDL Mode 2 data link system had been investigated as well.
Reason was simply that such systems were not available to DFS at the time the activities were conducted. Immediately after the end of the trials, VDL Mode 2 equipment was made available by ARINC, and the analyse-method described in this report will be applied to this system as well and results be reported as soon as available

In addition, the results presented in this report imply that a demand for more capable data link systems may arise from the applications, and such data link systems will have to be investigated in order to validate their potential use as soon as a reasonable capability for a wider use is acknowledged within DFS.

The integration of mobile data links into the test bed of DFS was started at the end of 1997 in the framework of the "ATN Trials Infrastructure" (ATIF) project. From the technical viewpoint, AMSS proved to be an unproblematic system which, after a short integration phase, could be used experimentally.

The integration of Mode S was far more difficult, since a large number of system problems and, above all, a lack of Mode S specialists had a lasting effect: Whereas external expertise was available for AMSS, this was possible only with limitations in the case of Mode S. This meant that a large amount of DFS resources had to be used for system trouble shooting instead for performance testing.

In the case of NEAN, DFS was involved in a separate project and provided 4 base stations, one national server and one monitor station for the European NEAN infrastructure.
Even though all these components were permanently used in the scope of the project NEAN, the comparative data link investigations revealed system failures. Fortunately, most of them could be resolved by the manufacturers in a short time.

Finding suitable test equipment for the comparative data link tests was another challenge. A market analysis showed that there were no suitable "off the shelf" systems, and orders were therefore placed for the development of a data link test equipment (Comparative Data link End-to-end Classification and Analysis Tool (CODECAT)), with the objective of providing systems with a modular and thus easily extendable design which could be used later for such purposes as the classification of various Data Links in accordance with the ATN Standards and Recommended Practices (SARPs) and also for other examinations.
It is currently becoming clear, as part of the VDL Mode 2 examinations, that this was the correct decision. It was possible to extend these systems quickly and cheaply so that they could be used for further tests.

0.2 Objectives

Within the framework of the development and evaluation of capacity-increasing technologies and procedures, DFS is actively involved in their standardisation. Especially the contributions to different international bodies of experts, which are in charge of the development and standardisation of these new technologies and procedures, reveal the need for a common methodology and measuring device to obtain comparable results with respect to performance, reliability or a potential benefit.

Various projects and programmes outside DFS deal and dealt with the analysis of the capacity provided by new data link systems (e.g. Automatic Dependant Surveillance (ADS) Europe Trials, Flight Trials of ATN over Multiple Subnetworks (FITAMS), ProATN, Investigation of Networked CNS/ATM Applications (INCA)). However, due to the different methods used to measure their potential, the results are often difficult to compare or even not comparable at all.

It was therefore an essential requirement to compare the different data links under equal conditions (as equal as possible) with the same measurement tools and measurement procedures, to:

- provide a basis for the decision process regarding the future use of different data links,
- present recommendations on how to classify data links (e.g. with respect to the classification scheme for mobile networks defined in the ATN SARPs, Package 2),
- derive recommendations for the optimisation of data link systems currently in use.

Furthermore, results presented in this document are targeted towards helping to optimise the use of data link services like CPDLC, ADS-B/C or FIS and the development of new ATM systems, provided the behaviour of the data link systems is taken into consideration.

0.3 Results

0.3.1 Measured Response Time

From the response time assessment it can be concluded that the AMSS and NEAN data links are in a position to support a range of data link services or, more specifically, these data link services for which response time requirements have been defined so far (see [8]). The Mode S data link fails to meet the defined requirements and can only be considered for non-time-critical data link services, such as Controller Access Parameters (CAP).

0.3.2 Integrity

Considering the integrity requirements defined by the ADS Panel (ADSP) and the measurement results collected during the data link trials, it can be noted that none of the investigated data links seems to be robust enough in order to meet the defined integrity requirements on the network level. However, it should be noted that the ADSP requirements refer to the end-to-end integrity, i.e. between applications hosted in end systems. This means that appropriate measures in the upper protocol layers of these end systems, such as checksums and sequence numbers on the transport layer and/or the application layer, may considerably improve the measured integrity on the network layer; experience and analysis [10] shows that integrity improvements in the order of several decades are achievable.

Consequently, the AMSS data link which has demonstrated an excellent loss rate in the uplink (i.e. 0 %) and a modest loss rate in the downlink (i.e. 0,1 %) meet at least the 10^{-6} end-to-end integrity requirement, given that such upper layer protocol mechanisms are applied. It may also meet the 10^{-7} requirement, however this requires a more detailed analysis.

The very high loss rates measured for the NEAN and Mode S data links (11,4 % and 24,1 % respectively), however, do not allow to arrive at the same conclusion w.r.t. the achievable end-to-end integrity as for the AMSS. This means that these data links are currently not expected to meet the integrity requirements postulated for the known air/ground applications, given the obtained measurement results. However, it should be noted that the observed high loss rate for the Mode S data link seems to be primarily caused by malfunction of the experimental equipment used in the data link trials. It is expected that operational Mode S equipment will exhibit a much smaller loss rate, which in combination with appropriate upper layer loss protection features may qualify this data link for support of air/ground ATS applications.

The high loss rate measured for the NEAN data link seems to be a system-inherent feature which may be attributed to the missing flow control mechanisms in this data link. If such flow control mechanisms are added, e.g. in the context of an ISO/IEC 8208 packet layer interface (the X.25 Protocol), and upper layer protection features are also implemented, then the NEAN data link is expected to be a candidate for supporting operational air/ground Air Traffic Services (ATS) applications (in the scope of the ADSP integrity requirements).

0.3.3 Reliability

Considering the reliability requirements defined by ADSP and the measurement results collected during the data link trials, it can be noted that none of the investigated data links seems to be robust enough in order to meet the defined reliability requirements. However, it should be noted that experimental equipment has been used in the data link trials which sometimes exhibited strange/undeterministic behaviour and/or was poorly debugged in some cases.

0.3.4 Throughput Assessment

The throughput assessment is based on a flight communication traffic profile which has been developed in the context of the ATN Implementation Task Force.

All investigated data links will be able to transfer the required traffic load per flight associated with the three traffic scenarios considered above. However, it should be noted that the measurements performed during the data link trials and the assessment made above hold for a single aircraft. In an operational environment a number of aircraft will share the capacity of a data link system. Consequently, there will be an upper limit of aircraft which may be simultaneously served by a given ground station. In the case of AMSS, this limit will be defined by the number of channels which may be simultaneously maintained by the ground earth station. In the case of Mode S and NEAN, this limit will be defined by the overall RF capacity offered by the data link system. This overall capacity depends on a number of factors, which are for example the rotation time of the antenna and the geographical distribution of the aircraft in the case of Mode S. Therefore a more detailed and sophisticated analysis would be required to expand the measurement results on a large scale operational scenario.

0.3.5 Summary of Results

Table 1 provides a high-level summary of the measurement results for the three investigated data link technologies. The values listed in this table should be understood as the 95%-values derived from multiple trials in various test environments and are intended to broadly classify the relevant data link technology for the subsequent assessment. The reader is referred to the following chapters for the detailed and accurate measurement results.

	AMSS		**Mode S**		**NEAN**	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
User Data Rate (bits/s)[1]	359	180	-[2]	-[2]	312	339
Packet Rate (packets/s)[1]	0,3	0,25	-[2]	-[2]	1,9	2,0
Transmission Delay (seconds)	11,0	28,0	72,1	51,7	6,2	4,4
Message Loss Rate (%)	0,0	0,1	9,2	24,1	11,4	2,8
Reliability (%)	46	41	51	52	56	44
Call Setup Round-trip Time (seconds)	4,7		29,1		n/a	

[1] The data rate and packet rate values are average values collected from a number of measurements with varying packet lengths; therefore no strict relationship exists between the listed values of these two performance characteristics.

[2] No data rate and packet rate could be measured for the Mode S data link; therefore a "-" is indicated in the associated boxes of Table 1.

Table 1: Performance Characteristics of the Investigated Data Links

0.4 Conclusion and Recommendations

Even if it still seems to be a long way to go before data link and ATN is operationally introduced, the comparative data link investigations were a significant step in that direction. Both, the results achieved and the infrastructure built at DFS's R&D centre in Langen are a foundation for continuing activities (e.g. the simulations, VDL Mode 2 investigations), new projects and future plans with respect to the introduction of data link in Germany.

Having carefully analysed the large amount of detailed results from the investigated data link systems, it becomes clear that there is no clear winner of the data link trials. All investigated data link technologies exhibit some deficiencies which will limit their deployment for operational data link services. The major identified deficiencies are:

- The extreme packet loss rate of the NEAN data link in the case that the incoming packet rate exceeds a certain threshold (i.e. more than 3 packets/second) due to the lack of flow control between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE)
- The large variations in the transmission delay of the AMSS data link which may be a problem for data link services which require a request-response transaction being completed within a given time interval
- The high round-trip times of the Mode S data link which exceed the maximum delay expected by the majority of currently envisaged ATS data link services.

0.4.1 Data Link Technology

Out of the investigated systems, there is no data link technology which suggests itself as a primary candidate for implementation. Based on the assessment presented in this document, AMSS will receive the highest ranking and Mode S the lowest one. However, none of the investigated data link technologies succeeds in meeting the complete set of requirements. In particular, in the categories reliability and integrity the investigated data link systems fall considerably short of the requirements; this may be attributed to the experimental and prototype character of the data link equipment used in the trials.

A lot of trouble arose from Mode S subnetwork component interoperability problems. This was disappointing since more work had been allocated to the systems' interworking, instead of their use.

It is also remarkable that none of the investigated data link systems seems to be a real good backup candidate for one of the other investigated data link systems. In particular, it is hard to imagine that a class H[1] system may be an appropriate backup or complementary system for a primary class C system.

The AMSS system used for these investigations is already based on commercial products which have been on the market for several years. In spite of this, it is even now not in a position to meet all of the requirements. Also the Mode S ADLP, a prototype

[1] See ATSC classification in chapter 8.2.1

system which incorporates the experience of several years, entailed various problems; and finally VDL (except Mode 1) is still in its technical infancy.

In conclusion the question arises if any data link may fulfil the stringent operational requirements in the near future.

0.4.2 Recommendations with respect to the use of mobile Data Links

Due to the immense gap between operational requirements and technical reality, it is obviously still a long way to go for data link system developers and data link providers. But it is also recommended to re-consider current concepts how data link could be used in the future, in particular with respect to time-critical messages.

It should be added as well that the data link investigations exposed a need for recommendations how to classify data links. A case in point is the message length which should be taken into consideration if a data link is classified. For instance, depending on the message length, the AMSS data link (downlink) may be for example an ATSC class C, class D or class E data link (with respect to the ATN classification scheme). Similar effects occur with Mode S and mechanically rotating antennas. This demonstrates that a classification which should provide a basis to compare different data links with each other or to find the adequate data link for a data link service respectively, doesn’t provide a suitable source of help if the results are not presented in conjunction with the measurement procedure they are based on.

It is currently emerging that an operational introduction of VDL Mode 2 as a primary data link is getting more and more likely. It is therefore an open question if one of the investigated data links could take over the role of a complementary data link for VDL Mode 2.

On condition that a complementary data link should support the same services as the primary candidate does, it is not possible to recommend any of the investigated Air/Ground data links to be used for that purpose in their current development status. The results achieved in the scope of the investigations make clear, that neither the measured performance values (integrity, reliability, end-to-end delay) nor the system behaviour fulfils the user requirements.
If it is foreseen to use a complementary data link just for some of the services that are supported by the primary data link, which means that the requirements for a complementary candidate are not as stringent as they are for the primary one, than a further assessment based on the services that are to be supported is recommended.

In the case of a complete substitution of the primary data link by the complementary one, it does not appear advisable to spend more money on the further development of these data links in order to use them as a complementary medium as part of a first data link implementation phase (for services which are not time-critical). Instead, activities should be concentrated on the development of complementary media for a second data link implementation phase, whose objective is the introduction of time-critical services (such as VDL Mode 3 or Mode 4).

We therefore recommend that work be concentrated on the strengths of the data links evaluated during the comparative data link examinations and that these be used for the above purpose. These could be the Mode S Specific Services and ADS-B for Mode S, ADS-B for NEAN and data transfer in areas without VHF or radar coverage for AMSS.

Nevertheless, if it is still planned to use one of the investigated data links as a complementary data link for VDL Mode 2, then the most promising candidate needs to be assessed based on the development potential and the associated effort with the applications in mind.

0.4.3 Recommendations with respect to the use of the ATN

Analyses carried out as part of the comparative data link examinations prove that the ATN can provide a noticeable improvement in the performance values (reliability, integrity). This is achieved by a set of International ISO (Organisation for Standardisation) protocols, such as ISO8208 (X.25), CLNP (Connectionless Network Protocol) or TP4 (Transport Protocol level 4).

In addition, ATN foresees very efficient compression algorithms for the air/ground communication which keeps protocol overhead in an acceptable range. This means that the overhead associated with the protocols above the data link system (which shall guarantee the required reliability and integrity) is in fact only partly seen by the data link system.

Finally, the Joint ATN Trials performed in 1997 showed that the ATN has no negative effects on the ground subnetworks which are used (such as the Packet Switched Network (PSN) of DFS).

On the basis of the ATN SARPs, which are now very well developed, the diverse available pre-operational systems (such as ProATN) and the extensive studies which have been carried out as part of various national and international projects on the subject of ATN, this technology probably offers the largest potential to be put into service in a short time in order to support the use of future Data Link Services.

1 Introduction

1.1 Structure of the Document

In the course of the comparative data link investigations, three mobile data links were investigated. These are the Aeronautical Mobile Satellite Service (AMSS) provided by INMARSAT, Mode S and NEAN.

The purpose of the investigations is summarised in chapter 2 whereas a brief description of the characteristics of the different data link technologies as well as an overview of their development history can be found in chapter 3.

Chapter 4 outlines the test procedures applied for the comparative data link investigations, the tools used and information about the transmitted user data.

The data link configurations under investigation are described in detail in chapter 5 whereas chapter 6 deals with the results which were obtained when using the configurations described in chapter 5 and their interpretation.

A comparison of the different data links based on the results is given in chapter 7.

Essential results and derived consequences for future mobile data link applications and for the Aeronautical Telecommunication Network (ATN) are summarised in chapter 8.

Appendix C describes the side effects observed in the course of these investigations.

1.2 Purpose of the Document

The increasing air traffic density is an enormous challenge for all those involved. Both the airlines and the air navigation service providers now have to act to fulfil the increasing demand.

Especially in busy airspace, currently used technologies and procedures have reached their maximum capacity and efficiency, which is the reason for the ongoing intensive work on the development of new air traffic management technologies and procedures.

In this area, data link plays a key role because it supports automation of ATS processes which will relieve pilots as well as controllers from routine tasks and improves efficiency of AOC and AAC operations.

New ATM procedures based on these systems can help to provide additional capacity to fulfil future needs.

This document describes the extensive evaluation and analysis process of the data link investigations and the results achieved by these investigations concerning the different data links with the objective to

- provide a basis for the decision process regarding the future use of different data links,
- present recommendations on how to classify data links (e.g. with respect to the classification scheme for mobile networks defined in the ATN SARPs, Package 2),
- derive recommendations for the optimisation of data link systems currently in use.

Furthermore, results presented in this document are targeted towards helping to optimise the use of data link services like CPDLC, ADS-B/C or FIS and the development of new ATM systems, provided the behaviour of the data link systems is taken into consideration.

1.3 References

[1] DFS Data Link Evaluierung “Definition der Versuche”, Version 1.2, Th. Schade, Dr. F. Ziegler, DFS; 06.07.1999

[2] AMSS SARPs, ICAO Annex 10, Volume III, Part 1

[3] Mode S SARPs, ICAO Annex 10, Volume III, Part 1 (Digital Data Communication Systems), and Volume IV (Mode S System), First Edition, July 1995

[4] Untersuchungen zum künftigen aeronautischen Satellitensubnetzwerk der Flugsicherung, Dr. Matthias Poppe, TU Braunschweig, 1996

[5] ADS-C/ATN/INMARSAT Data Link Transit Delay Analysis, Version 1.2, C. Tamvaclis, G. Rambaud, Eurocontrol, 10.02.1998

[6] NEAN - Final Project Summary and Conclusion Report, Version 1.0, NEAN Project Group, May 1999

[7] VDL Mode 4 in CNS/ATM Masterdocument, Version 1.0, Luftfartsverket, Swedish Civil Aviation Administration, 29.10.1999

[8] Eurocontrol, Operational Requirements for Air Traffic Management (ATM) Air/Ground Data Communications Services, Edition 1.0, 15 January 1998

[9] ICAO, Automatic Dependent Surveillance (ADS) and Air Traffic Services (ATS) Data Link Applications Guidance Material, ICAO ADSP/3 Report, Appendix B on Agenda Item 5, 9-24 May 1994

[10] ICAO, ATNP/1 UK Paper on Agenda Item 4, 8 – 21 June 1994

[11] Eurocontrol, Proposed European ATN Implementation Plan, Issue 1.0, EATMP/DIS/COM/ATN/ATNI-TF/DOC/37, 17 June 1999,

[12] ICAO, Proposed Draft Third Edition of Doc 9705 – Manual of Technical Provisions for the Aeronautical Telecommunication Network (ATN), Subvolume V – Internet Communications Service, February 2000

[13] Eurocontrol, COM.ET2.ST15: Analyse Options for Initial Air/Ground Data Networks, Phase 3 Report, Doc-No. COM.ET2.ST15.3000-REP-02-xx, 8. December 1997

[14] Eurocontrol, European Network Operation Concept (ENOC), System Model, Draft 3.0, 3. Juni 1994

[15] Report of the DLK users form held 3-4 February 1999 in Orlando (Florida), 26. February 1999

[16] Eurocontrol, COM.ET2.ST15: Analyse Options for Initial Air/Ground Data Networks, Executive Summary, Doc-No. COM.ET2.ST15.0000, Edition 1.0, 15. October 1998

[17] Core ATN Standards and Recommended Practices, ICAO Annex 10, Volume III, Part 1, Chapter 3

[18] Manual of the Technical Provisions for the Aeronautical Telecommunication Network (ATN), ICAO Doc 9705, 2nd Edition, 1999

[19] *Draft* Comprehensive ATN Manual (CAMAL), ICAO Doc 9739, 1999

[20] Eurocontrol: Validation of Mode S Subnetwork SARPs, Final Report, Doc-No. SUR3.ET2.ST03.4104, Edition 1.0, 29. September 1998

[21] Eurocontrol: Investigation of Future Traffic Scenarios and Data Link Loadings Using the Mode S Data Link Model, SICASP WP1/508, London, April 1996

2 Objectives of Experiments

2.1 Purpose of Experiments

Within the framework of the development and evaluation of capacity-increasing technologies and procedures, DFS is actively involved in their standardisation.

Especially the contributions to different international bodies of experts, which are in charge of the development and standardisation of these new technologies and procedures, reveal the need for a common methodology and measuring device to obtain comparable results with respect to performance, reliability or a potential benefit.

Various projects and programmes outside DFS currently deal with the analysis of the capacity provided by new data link systems (e.g. ADS Europe Trials, FITAMS, ProATN, INCA). However, due to the different methods used to measure their potential, the results are often difficult to compare or even not comparable at all.

With the Demonstrator and ATN Research Test Bed (DART) project, DFS has developed a trials infrastructure to actively support the ATN SARPs validation and, in addition, to evaluate different data links (AMSS, Mode S, VDL Mode 2) with regard to their usefulness for a future ATM system.

With the North European ADS-B Network (NEAN) Infrastructure, a further mobile data link became available which was included in the comparative data link investigations.

The main objective was the comparison and evaluation of different mobile data links with regard to their reliability and efficiency (usefulness) in a similar environment under similar conditions.

2.2 Methodology

The comparative data link investigations were divided into two phases. The first phase focused on the preparation of the concept, plan and test environment for the data link investigations whereas the second phase, itself divided into steps, concentrated on performing the investigations and producing the final report.

Milestones of the two programme phases were the preparation of the concept for the investigations (end of phase 1), the development of data link test tools (step B1), the two trials-campaigns (laboratory (B3) and flight trials (B5)), and finally the preparation of this report.

The different work packages and their interrelation are illustrated in Figure 1.

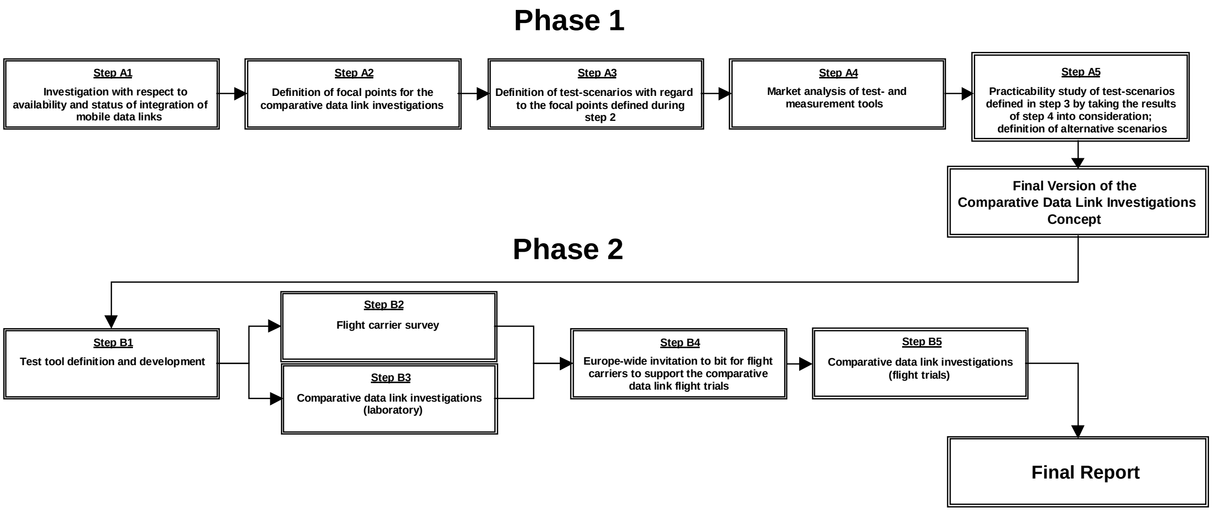

Figure 1: Sequence of work packages of the comparative data link trials

All three data links were investigated with regard to their up- and downlink properties. This means that every test (connection establishment, data transmission latency, etc.) was performed twice. In addition to these investigations on the network layer, investigations were performed on the application layer using the Controller to Pilot Data Link Communication (CPDLC) application specified in the ATN SARPs and the two ATN subnetworks (i.e. AMSS and Mode S).

Based on the results achieved by the laboratory trials campaign, flight trials were performed similarly to the laboratory trials (up- and downlink) but with the priority on the interaction of flight manoeuvre and data transmission behaviour.

In parallel to the distribution of this report, further investigations are performed using the VDL mode 2 data link. It’s planned to incorporate these results in this report which is to be expected for the third quarter 2000 as a version 2.0.

3 Background

3.1 VHF Digital Link (VDL)

The ICAO definition for the VHF Digital Link (VDL) is:

The VHF digital link (VDL) is a constituent mobile subnetwork of the aeronautical telecommunication network (ATN), operating in the VHF aeronautical mobile frequency band. The VDL may in addition provide non-ATN functions such as digitised voice.

Presently there are 4 VDL Modes under standardisation by ICAO. Each Mode represents a different system and there is only a limited interoperability between the Modes. Each VDL standard has broadly the same subnetwork architecture for ATN communications. VDL Mode 3 and 4 have additional non-ATN services.

The radio channel selection is based on the 25 kHz VHF voice channel division. For the world-wide VDL implementation 4 frequencies in the 136.900 MHz to 137 MHz band are available. It must be noted that a guard band is necessary between a VDL used frequency channel and a voice channel because of the characteristics of the digitally modulated signal. For a D8PSK digital modulated channel the guard band is ±75 kHz (3 frequency channels), the guard band for a GFSK digital modulated channel is smaller but not yet defined. Further analysis is required.

The re-organisation of the VHF frequency band from 25 kHz channels to 8.33 kHz channels will bring up 4 additional VDL channels in 2003. Referring to the current frequency planning the additional VDL channels will be located in the upper VHF band (136.800 MHz to 136.900 MHz), too.

3.1.1 VDL Mode 1

The VDL Mode 1 data link is based on the existing ACARS infrastructure, which uses the AM-MSK (Amplitude Modulated Minimum Shift Keying) modulation scheme. It is a character oriented data link using CSMA (Carrier Sense Multiple Access) access scheme with a net data channel rate of 2.4 kbps[1].

The VDL Mode 1 was specified in order to provide a fall back solution for the use of the VDL Mode 2 to utilise VDL protocols with a well-validated physical layer. Because it is expected to have a VDL Mode 2 system operationally in use, it is unlikely to bring out the VDL Mode 1 in operation.

The VDL Mode 1 SARPs have completed the ICAO standardisation process and are incorporated into the Annex 10.

3.1.2 VDL Mode 2

VDL Mode 2 is a bit-oriented data link using D8PSK (Differentially encoded 8-Phase Shift Keying) modulation scheme and CSMA (Carrier Sense Multiple Access) access scheme. The net data rate for a single VDL Mode 2 channel is 31.5 kbps[1].

[1] Note that the channel capacity has to be shared amongst all equipped aircraft within the coverage of the same ground station.

The CSMA algorithm provides an arbitrary access to the radio channel. This makes it more difficult to meet the service levels required for time-critical ATM messages. The use of CSMA gives acceptable performance at low traffic loads, but if the traffic load on the network gets higher, the access time to the shared RF medium increases exponentially and the access time will no longer meet the operational requirements. It is therefore unlikely that VDL Mode 2 will be used for time-critical ATM applications, e.g. tactical CPDLC messages.

The VDL Mode 2 SARPs have completed the ICAO standardisation process at the same time as the VDL Mode 1 SARPs. It is planned to build up an operational VDL Mode 2 network in the near future.

3.1.3 VDL Mode 3

VDL Mode 3 is also a bit oriented data link using D8PSK (Differential 8 Phase Shift Keying) modulation scheme providing 31.5 kbps[1] net data rate. The medium access scheme is TDMA (Time Division Multiple Access). In addition to the ATN data link communication capability VDL Mode 3 supports voice communication on the same channel.

The VDL Mode 3 system requires 1 frequency per region, which is the area bounded by line-of-sight coverage. To ensure coverage in a larger area 6 to 8 frequencies are required.

The objective of the VDL Mode 3 architecture is to support a spectrum-efficient voice system using a digital data link system. Therefore it is proposed as an alternative to the reduction of channel spacing to 8.33 kHz for voice communication.

The system is being proposed by the U.S. FAA for ICAO standardisation, but not considered for the moment by ATM service providers for deployment in Europe.

3.1.4 VDL Mode 4

VDL Mode 4 is a bit-oriented data link using the STDMA (Self-organising Time Division Multiple Access) access scheme. In the Draft SARPS two modulation schemes are defined: GFSK (Gaussian Filtered Frequency Shift Keying) providing 19.2 kbps[1] data rate and D8PSK (Differentially Encoded 8 Phase Shift Keying) providing 31.5 kbps[1] data rate for a single frequency channel.

While VDL Mode 3 relies on ground stations to provide the channel synchronisation signal for the TDMA access scheme, VDL Mode 4 is a self-synchronising system that uses any sort of time system (e.g. GNSS or Flight Management System (FMS) time signals) to synchronise in the absence of ground stations.

VDL Mode 4 was designed to provide a system for communication, navigation and surveillance applications. In addition to the ATN compatible communication part the system provides a specific communication protocol called VDL Mode 4 Data Link Service (DLS) and a navigation and surveillance part based on the ADS-B application.

[1] Note that the channel capacity has to be shared amongst all equipped aircraft within the coverage of the same ground station.

A significant benefit of the VDL Mode 4 Data Link Service protocol is that the slot reservation protocol can be used to provide communication on pre-reserved slots. This reduces the probability of simultaneous transmissions by 2 transponders.

The VDL Mode 4 data communication is illustrated in Figure 2. The station wishing to send data sends a Request_to_Send message providing details of the information frames to be sent. In the same message Station 1 places a unicasted reservation for Station 2's subsequent response. Station 2 acknowledges this request and issues an Authorisation_to_Send data. Station 2 simultaneously reserves slots for the information transfer and for its own subsequent acknowledgement. Station 1 can then send the data in the reserved slots. Finally Station 2 acknowledges the data and can request re-transmission or transmission of additional data, once again including the reservation message for the appropriate slots.

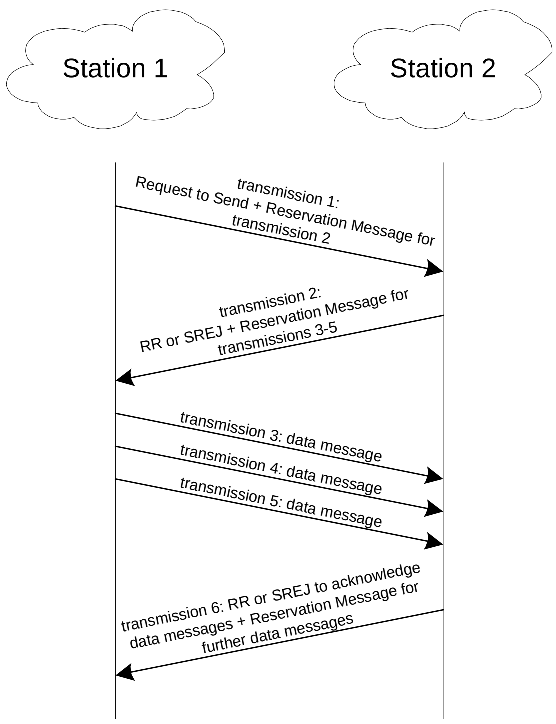

Figure 2: VDL Mode 4 data transmission (DLS protocol)

Only the first transmission has no previous reservation, although it may be possible to place a reservation for this transfer during a previous transaction. Further VDL Mode 4 supports a short transmission protocol for transfer of short information blocks.

Presently there is no VDL Mode 4 equipment available. To demonstrate the functionality of the STDMA access scheme experimental STDMA equipment is used in different projects such as the North European ADS-B Network (NEAN).

3.1.5 NEAN

The North European ADS-B Network (NEAN) project was co-funded by the European Commission to develop, evaluate and demonstrate the STDMA technology for ADS-B purposes.

3.1.5.1 Self-Organising Time Division Multiple Access (STDMA)

The GNSS transponders used in NEAN communicate on a VHF radio data link, using the Self-organising Time Division Multiple Access (STDMA) technique. On this data link each transponder frequently transmits a position report which is received by all other transponders in the vicinity. Additionally a number of messages can be transmitted, such as differential corrections from a ground station, warning and status messages and text messages between transponders. The transmission is performed in time slots, which are shared by all transponders in the vicinity of the ground station, see Figure 3 below.

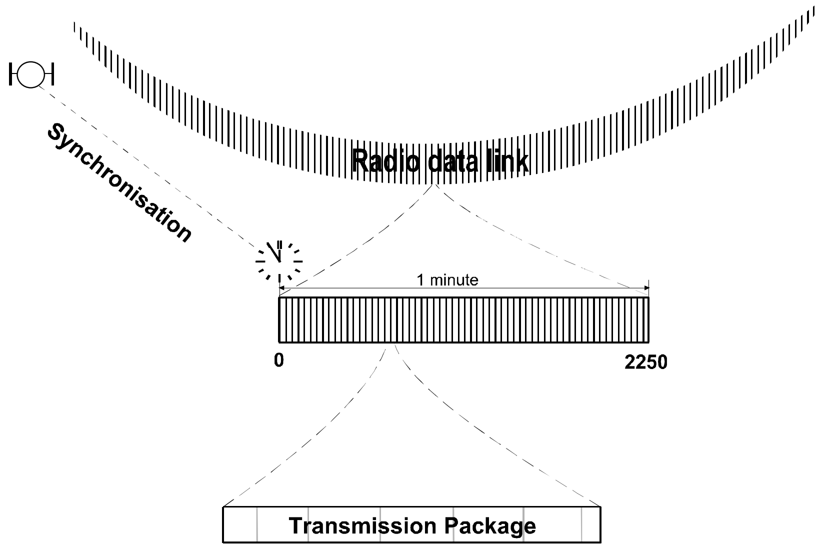

Figure 3 - The time slots on the radio link

The number of time slots per minute depends on the bandwidth and transmission rate of the radio channel. The project used a bandwidth of 25 kHz and a transmission rate of 9600 bps. A slot size of 256 bits (32 bytes) gives 2250 time slots per minute.

3.1.5.2 NEAN Data Link Functionality

The NEAN system provides basic data link functionality where data link messages were transmitted using the random access protocol. This means that text messages are being transmitted without a prior reservation of a time slot. A transponder wishing to transmit a text message selects a time slot which was not reserved by another transponder in advance. If another transponder also tries to transmit a text message in the same slot a collision occurs. This means that in contrast to VDL Mode 4 for the NEAN data link functionality, only a TDMA access method is used. As shown in Figure 4 all data link messages are transmitted without former slot reservations.

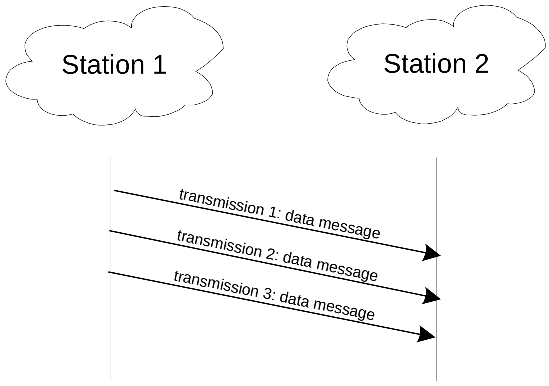

Figure 4: NEAN data transmission

3.1.5.3 Synchronisation

Since several transponders are to share the time slots, it is of high importance that all transponders transmit on exact times to avoid overlapping transmissions. An internally corrected and synchronised time in each transponder provides this functionality.

3.1.5.4 Transmission Format

The messages on the data link are transmitted in packets, which include a number of frames, such as start and stop frames and buffering.

3.1.5.5 Time Slot Allocation

The allocation of time slots can be controlled in two different ways, either in autonomous mode or in controlled mode. In autonomous mode each transponder automatically looks for vacant time slots.

In controlled mode a ground station assigns time slots to the transponders in the area. A ground station can work either in autonomous or controlled mode. The mode is chosen at set-up. The controlled mode can be used for transponders within the zone of a controlling ground station. When a controlling ground station receives an autonomous transmission, it determines if the mobile transponder is within its zone and, if it is, assigns time slots for the mobile transponder. The mobile transponder is thereby set in controlled mode. If a mobile transponder does not receive any time slot information from a controlling ground station, it automatically switches back to autonomous mode.

Base stations normally use autonomous mode in which they do not control the time slots of any mobile transponders. The only fixed slots used by a ground station in autonomous mode are those used for the up-link of differential corrections, if available.

3.1.5.6 Autonomous Mode

In autonomous mode each transponder listens for vacant time slots to use and reserve for future transmissions. This is the Self-organising Time Division Multiple Access (STDMA) functionality. The principle is shown in Figure 5.

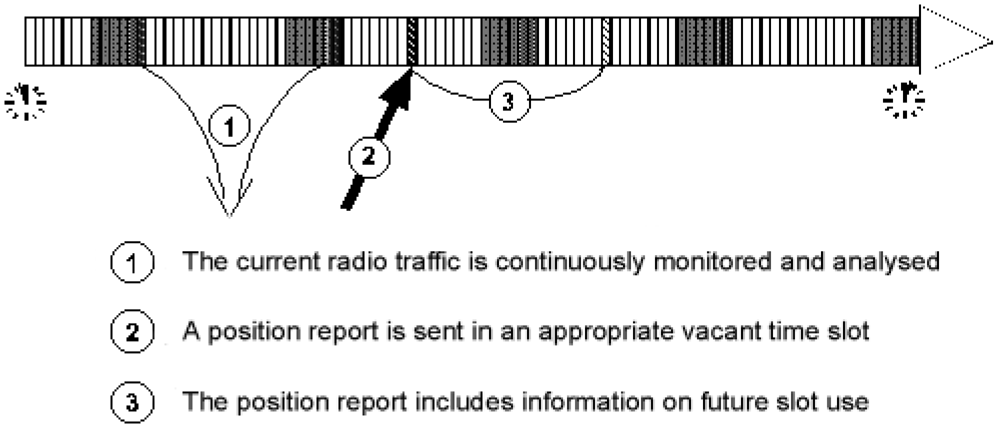

Figure 5 - The self-organising time slot mechanism in autonomous mode

The transponder monitors the data on the link and generates tables of the current radio traffic. The tables are continuously updated and vacant time slots are registered. A vacant time slot is selected in accordance with the requested update rate, and a position report is transmitted. The position report also contains information on how long the transponder will continue to send in the same time slot or in which time slot the next message will be sent.

Each transponder periodically changes the allocated time slots after a new evaluation of the current radio traffic. This is to avoid time slot collisions for example when new users enter the system.

If a transponder in autonomous mode receives a message from a controlling ground station or a transponder in controlled mode, the use of the nearest time slots is avoided. This is to give a controlling ground station spare slots into which it can direct transmissions from controlled transponders.

3.1.5.7 Controlled Mode

In controlled mode, a ground station distributes the allocation of time slots. The controlling ground station assigns time slots to all transponders within its zone, according to the requested update rate. If the ground station is equipped with a GNSS reference receiver, time slots are also assigned for differential correction data. Some slots are always left free in order to allow new users to enter the system, and for the slot changing process. Time slots can also be reserved for transmission of text messages or external data.

When controlling ground stations are installed, each ground station is assigned a sequence of time slots to use. In this way a controlled mobile transponder can always tell which ground station controls it if several are within range.

3.1.5.8 Main Properties

The NEAN STDMA system was designed for ADS-B purposes. Therefore the system provides only basic data link functionality. ATN compatible data link functionality is not provided by the system. The maximum message length handled by the system is 52 characters.

Property	
Carrier Frequency	136.950 MHz
Modulation scheme	Gaussian Minimum Shift Keying (GMSK)
Bit rate	9.600 bps
information unit	1 slot = 64 Bit
Addressing	48 bit addresses
channel Access scheme	Self-Organising Time Division Multiple Access
Time Base synchronisation	GPS
Interface protocol used in typical implementations	ASCII / RS232

Table 2: Main Properties of the North European ADS-B Network (NEAN)

3.2 Mode S

3.2.1 Background

The classical Secondary Surveillance Radar (SSR) is now in existence for several decades as a co-operative surveillance system utilising an active transponder in the aircraft. The SSR system is primarily used for surveillance in ATC, but even the classical SSR system did already allow to extract a very limited amount of additional data from the aircraft transponder, namely the barometric altitude (Mode C) and an identification of the aircraft (Mode A). Both parameters are normally displayed on the ATC controller's working position as an aid to identify a particular target and its altitude.

Certain shortcomings of the classical SSR system, such as Mode A code shortage, have led to the development of a new functional mode. The new mode allows to selectively address the individual aircraft transponders and is therefore called SSR Mode S ('S' for selective). It does not only allow to address each individual transponder in the radar coverage but also provides a more capable data link than the classical SSR does. SSR Mode S will complement or replace the currently existing SSR Modes A and C in the near term.

Due to its improved capability to transfer data, SSR Mode S may now be viewed under two aspects, which are (i) surveillance and (ii) data link. According to its objective this report only deals with the data link capabilities of SSR Mode S.

The SARPs of the SSR Mode S system were primarily developed between 1980 and 1995. The SSR Mode S ground systems are currently undergoing pre-operational evaluation while more than 50% of the commercial aircraft carry SSR Mode S transponders today as part of their ACAS systems.

Due to the frequencies used Mode S is designed to support all functions related to surveillance applications. Since it was noticed that future applications will require data transfer data link and communication capabilities were integrated. In its elementary form Mode S provides the same information as conventional radar. However, due to the chosen modulation and integrated error detection and error correction data transfer is already more reliable. In addition, more data like flight status or aircraft identification are part of this elementary form.

More data are to be transferred using Mode S Specific Services. These services can provide specific on-board data frequently updated in transponder registers for airborne and ground users. Bi-directional data transfer is offered by 63 Mode Specific Protocol channels. All these services are Mode S specific and not ATN compatible, but intended to ensure short access times for surveillance applications and operation even if ATN is not implemented.

Full ATN compatible operation is supported by the Mode S Subnetwork. As such it supports all data link services requested by ATN upper layers.

According to its objectives this report deals with data link capabilities of Mode S only. Unfortunately, no means were available to demonstrate and investigate Mode S Specific Services operation. Therefore, this report is limited to the analysis of currently available equipment for Mode S Subnetwork operation.

3.2.2 Technical Details

The classical SSR requires a ground interrogator sending interrogations by means of a rotating directional radar antenna. These interrogations are received by all transponders in the antenna beam. Upon reception of an interrogation all transponders in that beam generate an active reply signal. SSR ground interrogators allow to obtain the relative target positions by the antenna beam and the measurement of the propagation delay. The new SSR Mode S function operates on the same frequencies but with different signal formats to allow selective interrogations. Both the classical and the Mode S systems are interoperable.

The SSR uplink (ground-to-air) interrogations are sent at a frequency of 1030 MHz. Individual data telegrams used by SSR Mode S are called a format. On the uplink they consist of either 56 or 112 bits at a physical (net) data rate of 4 Mbps[1] using DPSK modulation. The selection of the individual transponders is achieved by a unique ICAO 24-bit address, which is assigned to each individual aircraft. Each format contains the aircraft address and allows the transponders to reply selectively. In general each interrogation triggers a transponder reply on the downlink (air-to-ground) frequency of 1090 MHz which also has a length of either 56 or 112 bits at a physical (net) data rate of 1 Mbps using PPM modulation. Information can be sent on the up- and downlink. Each data format contains a 24-bit CRC checksum to protect the data from corruption.

Standard length message formats (SLM) can be combined to bursts of up to 4 consecutive telegrams in order to form longer up- or down link message frames. Applications requiring more than 28 bytes on the air ground link are expected to use extended length message (ELM) formats allowing data transfer of 20 to 160 bytes per aircraft and scan. All communication activities are controlled by the ground system which also initiates retries if it does not receive a reply in response to an interrogation.

An information transfer between a particular transponder and an interrogator (or vice versa) can only take place when the (rotating or E-Scan) SSR radar antenna points in

[1] Note that this channel capacity has to be shared amongst all equipped aircraft within the antenna beam and adapted to the time the antenna beam is on the target.

the transponder direction. Otherwise messages need to be temporarily stored in the transponder or interrogator, respectively. The rotating radar antenna consequently introduces certain delays into the message transfer duration, which are also observed in the trials. Alternatives for the rotating antenna have been studied. They are partly or fully electronically steerable antennas (e-scan antenna) or omni-directional antennas (only useful for data link purpose in less dense airspace).

The exchange mechanism described so far relates to the physical (layer 1) and data link layers (layer 2) in the OSI sense. In the Mode S framework also a network sublayer (part of layer 3) is defined which provides network services to communication users. The SSR Mode S network layer conforms to the ISO/IEC 8208 packet layer protocol. Consequently, the Mode S subnetwork provides DCE interfaces on both SNACPs to which the test equipment used in these trials is connected. The data link parameters observed at these ISO/IEC 8208 DCEs are subject of this study.

3.2.3 Main Properties

The main properties of the SSR Mode S system are summarised in Table 3.

Property	Uplink	Downlink
Carrier frequency	1030 MHz	1090 MHz
Modulation scheme	Binary Differential Phase Shift Keying (DPSK)	Binary Pulse Position Modulation (PPM)
Bitrate	4 Mbit/s	1 Mbit/s
Smallest information unit	56 bits	56 bits
Longest information unit	16 x 80 bits	16 x 80 bits
Error Protection	24 bit CRC Error detection	24 bit CRC Error correction
Addressing	24-bit addresses	24-bit addresses
Channel access method	Spatial Division Multiple Access/ Time Division Multiple Access	Access controlled by uplink
Principle access delays	dependent on rotation speed of antenna (usually 0s - 12 s)	Same as uplink
Interface protocol used in typical implementations	ISO/IEC 8208 / LAP-B	ISO/IEC 8208 / ARINC 429-Williamsburg

Table 3: Main Properties of the Mode S Subnetwork

3.3 Aeronautical Mobile Satellite Service (AMSS)

3.3.1 Background

The use of satellite communications is the only reliable means (with HF as the only potential competitor) to assure an efficient communication means, not only in oceanic or remote areas but also in countries with a poor ground infrastructure.

To fulfil these needs, the INMARSAT service has been developed in co-operation with the International Civil Aviation Organisation (ICAO), the Airlines Electronic Engineering Committee (AEEC), the European Organisation for Civil Aviation Equipment (EUROCAE), Aeronautical Radio Inc. (ARINC) and Société Internationale de

Télécommunications Aéronautiques (SITA). The service is intended for passenger communications (APC), airline operational communications (AOC) and air traffic control (ATC) communications, both for private and commercial aircraft.

In the current constellation the INMARSAT Space Segment, which has been designed to provide voice and data services, comprises nine geostationary (36000 km from earth) satellites of which five serve as a backup. This ensures a global or quasi-global coverage (except in the polar areas).

Four active satellites of INMARSATs third satellite generation “INMARSAT-3” have been placed in addition to the existing INMARSAT-2 satellites in 1996 and 1997. These new satellites brought further improvements into the system, like spot beam capability resulting in higher EIRP (plus 9 dB compared to INMARSAT-2),therefore allowing higher bit rates for data transmission. On 4 February 1998, the fifth INMARSAT-3 satellite was successfully launched and added to the system as a spare satellite.

Each active satellite is served by a number of Ground Earth Stations (GES). From central Europe three active satellites can be reached.

DFS uses the Atlantic Ocean Region East satellite. This satellite is served amongst others by the Ground Earth Station (GES) in Aussaguel/France, which offers the character-oriented data-2 service as well as the data-3 service.

3.3.2 Technical Details

On board of an INMARSAT-equipped aircraft, a radio-terminal called Aircraft Earth Station (AES) is utilised to send and transmit voice and data messages. The INMARSAT satellites operate as relay-stations which convert the signals from the L-Band (1.5/1.6 GHz) into the C-Band (4.1/6.4 GHz). The data-processing on the ground is done by a Ground Earth Station (GES) which may be connected with public ISDN and X.25 networks as well as with aeronautical network providers like SITA and ARINC or ATC centres respectively.

An overview over the INMARSAT communication chain is given in Figure 6.

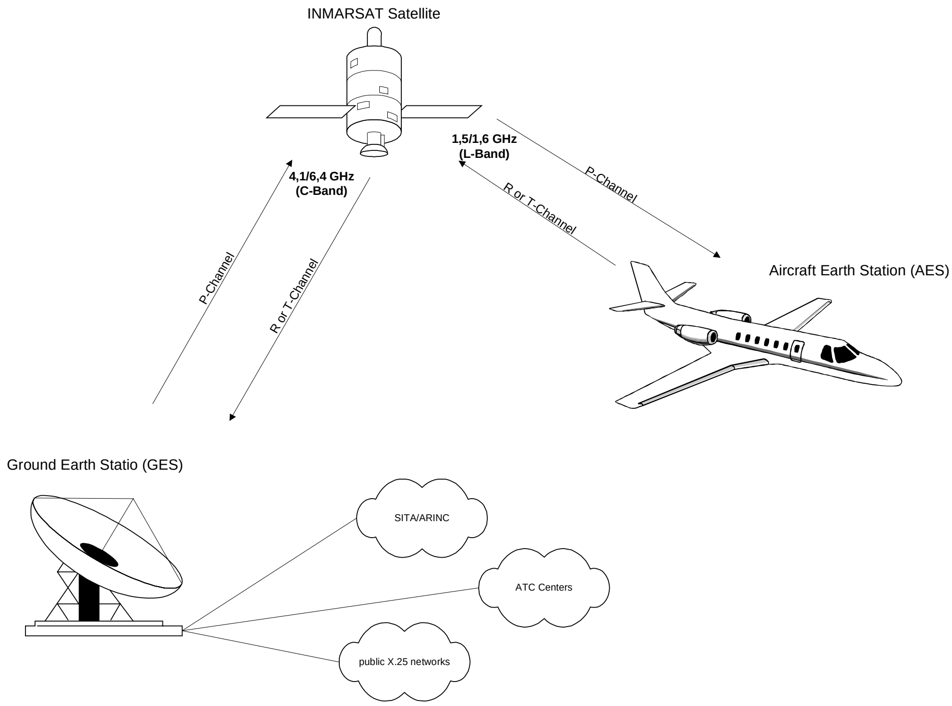

Figure 6: INMARSAT communication chain

3.3.2.1 Aircraft Earth Station (AES)

The AES which is installed in the aircraft, consists of a Satellite Data Unit (SDU), a High Power Amplifier (HPA), an optional Radio Frequency Unit (RFU), a low-noise amplifier/diplexer, an antenna control unit, and a suitable antenna (low, intermediate or high gain antenna).

The *SDU* provides the interfaces to communicate with the airborne data- and voice equipment. Furthermore it is responsible for system control and monitoring, data flow control, data (de-)modulation and the (de-)coding.

The *HPA*, a linear power amplifier, operates in the L-Band (1.5-1.6 GHz), and provides usually up to 40 watt output power which is controlled by the SDU, depending on the quality of the connection between satellite and AES.

AESs are divided into four classes (in accordance with the AMSS Manual), depending on the antenna used:

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

Table 4: AES classes

They have specific capabilities in terms of the rates they can support. All AES and GES can operate with the P and R Channels at 600 bps. The logon handshake always starts at 600 bps and then the GES determines the appropriate transmission rate to be used based on the received signal quality and the satellite used.

3.3.2.2 Ground Earth Station (GES)

The GESs, which operate in the C-Band (4,1/6,4 GHz), provide the interfaces to different terrestrial telecommunications networks, e.g. public X.25 and ISDN networks and such networks which are exclusively used by aeronautical users (SITA, ARINC). In addition, a GES manages the AES during log-on and log-off process, it controls and allocates the logical channels and communicates with the Operations Control Centre of INMARSAT.

The GESs are generally owned by consortia of terrestrial communication service providers (e.g. PTTs). In Europe the main GES supporting the INMARSAT aeronautical service are those at Aussaguel (France), Goonhilly (UK), and Eik (Norway). The Aussaguel GES is owned by the Satellite Aircom Consortium (France Telecom, SITA), while Goonhilly and Eik are owned by the Skyphone Consortium (British Telecom).

3.3.2.3 Satellites and Channel Types

The INMARSAT satellites operate as relays between the AES and GES. The AES, when activated, tries to “logon” via a satellite to a GES (usually according to a configurable preference list). Telephony and data communications with terrestrial systems can only take place while the AES is logged on to a GES.

The INMARSAT aeronautical system uses separate frequency channels for uplink (GES to AES) and downlink (AES to GES). Uplink is always via a P-Channel, while downlink can be via either an R or a T Channel depending on the message size. The P,R, and T channels can operate at rates from 600 bps to 10500 bps depending on the capabilities and configurations of the GES and the AES.

The three channel types are explained below:

R-Channel: Random access (slotted Aloha) downlink channel – burst mode transmission

The R-Channel is used for short data messages (≤ 33 bytes) and also for signalling. Packets are transmitted in a quantified fixed time interval which is obtained from the P-Channel. Compared with the T-Channel, a reservation is not necessary. This leads to a short delay time but requires a low channel utilisation of approximately 15 % in maximum. It is therefore recommended that the GES provides a sufficient number of physical channels to meet this demand.
There are two R-channel types, Rsmc and Rd, which may in fact share the same physical channel. The Rsmc-channel is used for system signalling functions such as log-on and call requests. The Rd channel is used for data transmissions.

T-Channel: Reservation Time Division Multiple Access downlink channel - burst mode transmission

The T-Channel is used for long data messages (> 33 bytes). The AES has to downlink first a transmission request using the R-Channel. In accordance with the signalled packet size, the GES reserves the required time slots and signals it via the P-Channel to the AES. During these time slots, the channel is exclusively reserved for the requesting AES. This procedure allows in theory a channel use up to a capacity of 100 %. Nevertheless it is recommended that a GES may have multiple T Channels to avoid a channel use to capacity of more than 80 %.

P-Channel: Packet Mode Time Division Multiple Access uplink channel - continuous data transmission.

The P-Channel is used for the transmission of data packets, system- and control information. It is furthermore the reference for the synchronisation of the R- and T-Channel.
The maximum number of channels is not limited by the bandwidth but by the radiation power of the satellites.
There are two types of P-channel: Psmc (system management and control) and Pd (data).

Psmc-channel is continuously broadcast by each GES to inform users of system status and configuration. It also carries the time and frequency information needed by AES wishing to log on to the system. Because of its importance for system integrity, the Psmc-channel has the most robust transmission link design of all channels.

Pd-channels are used for signalling and carrying ground-to-air data messages. The system has been designed to support a number of Pd-channels in anticipation of continuing traffic growth. Both types of channels, Psmc and Pd, may be combined on a single physical P-channel.

3.3.2.4 Link Layer Services

The INMARSAT aeronautical system provides full duplex packet data communications services using combinations of the P, R and T-channels.

Both control information and user data that are to be transmitted through the INMARSAT satellite system are formatted into Signal Units (SUs). Longer messages are divided into a set of SUs, depending on the channel used for data transmission. A single SU is called Lone Signal Unit (LSU), in the case of divided messages, the fist unit is called Initial Signal Unit (ISU) and following units are entitled Subsequent Signal Units (SSUs).

A SU transmitted via the P- and T-Channel has a size of 12 bytes whereas an R-Channel SU is 19 bytes large.

Each SU set is transmitted in the T-Channel as a single burst up to the maximum of 18 (600 bps) or 31 SU (10500 bps). Each R-Channel RF burst transmits a single 19 byte SU. All the SU include a 16-bit checksum.

The P and T Channel ISU may contain up to 4 user data bytes while each SSU may contain up to 8 user data bytes. The R-Channel SU may contain up to 11 user data bytes.

3.3.2.5 Packet Mode Data Services

The INMARSAT Aero Service provides two levels of packet data services, namely

Data-2

The Data-2 service which is similar to the VHF ARCAS service, is a connectionless character-oriented service. Data packets are transmitted individually. For that reason a data stream is to be converted into a limited character-string.
A network layer is not supported by the Data-2 service. It is consequently not compliant with the ATN SARPs.

Data-3

The Data-3 service supports an ISO/IEC 8208 interface and is therefore compliant with the ATN SARPs.

3.3.3 Main Properties

The main properties of the AMSS system are summarised in Table 5.

Property	Uplink	Downlink
Coverage	near global	near global
Carrier frequency	4.1/6.4 GHz	1.5/1.6 GHz
Modulation scheme	A-BPSK A-QPSK	A-BPSK A-QPSK
Bitrate	600-10500 bps	600-10500 bps
Information Unit (SU)	12 bytes (P-Channel)	12 bytes (T-Channel) 19 bytes (R-Channel)
Addressing	X.121	X.121
Channel access method	Packet mode TDM	Random access slotted ALOHA Reservation TDMA
Interface protocol used in typical implementations	ISO/IEC 8208 LAP-B	ISO/IEC 8208 ARINC 429-Williamsburg

Table 5: Main properties of the AMSS Subnetwork

4 Trials Environment

4.1 General

The trials were performed with the purpose-built CODECAT (COmparative Data link End-to-end Classification & Analysis Tools) environment. CODECAT is a toolset capable of analysing and classifying end-to-end performance parameters of data links and ATN subnetworks. The CODECAT toolset consists of the CODECAT Data Link Test Equipment (DLTE) and the CODECAT Pre-Processing & Evaluation Software (PES).

4.2 Data Link Test Setup

The different data link systems, described in detail in chapter 5, were investigated by the CODECAT environment as shown in Figure 7.

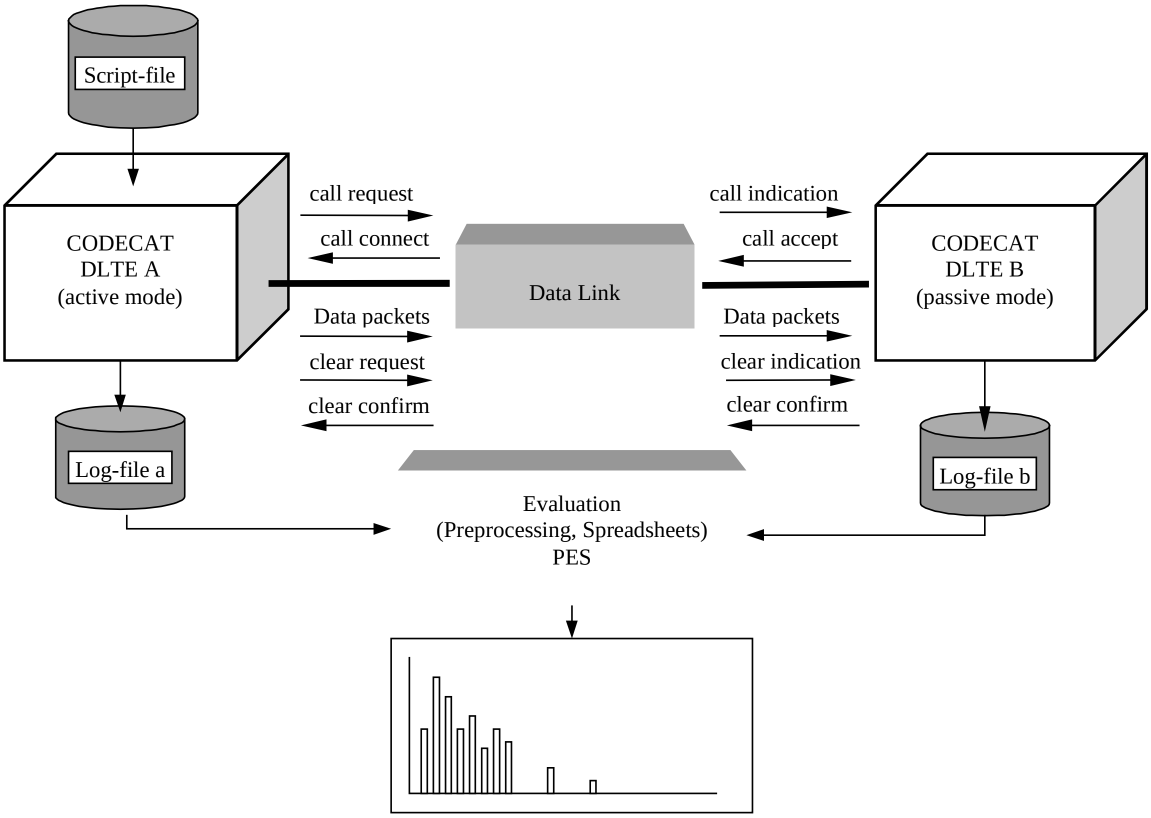

Figure 7: General Test and Evaluation Setup for the Investigation of the Data Links.

Figure 7 shows the two different elements of the investigations. In the upper part it displays the actual test execution setup while the lower half shows the evaluation process. The same split can be found in the activities performed during the trials:

1. Performance of the actual tests by means of the DLTEs
2. Evaluation of the resulting log-files by means of the PES

DLTE (A) sends ISO 8208 Call_Requests, Clear_Requests and Data packets as listed in the test-script and receives Call_Connect and Clear_Confirmation packets. The related events are time-stamped and stored in log-file 'a'.

DLTE (B) receives Call_Indications, Clear_Indications and Data packets and sends Call_Accepts and Clear_Confirmations back to DLTE (A). The related events are time-stamped and stored in log-file 'b'.

Tests were performed with a large number of messages in order to get an almost stable set of samples. The tests therefore had to be performed automatically. At the beginning of a test the test operator had to set up the data link and the DLTEs and to start the test run. After some hours the tests were finished and the log-files could be used for evaluation.

The log-file data was then evaluated by the CODECAT PES.

4.3 Application Layer Setup

For the application layer test-setup no dedicated tester like the DLTE was used. The test-setup was constituted by two Trials ATN Routers (TAR), Trials Transport Server (TTS), Trials End System (TES) software and FITAMS CPDLC Application Software. This testsetup was connected to the AMSS or Mode S data link, respectively. The overall application layer trials configuration is shown in Figure 8.

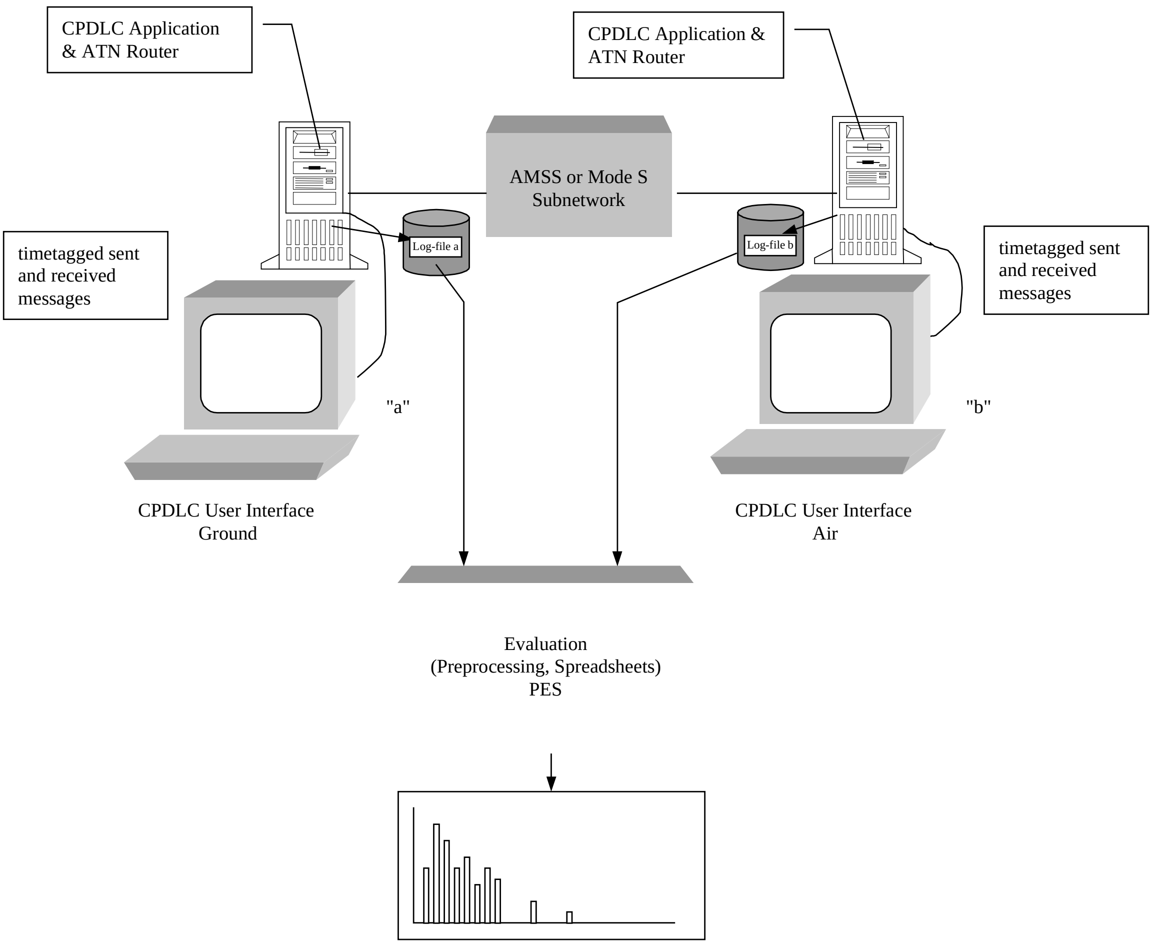

Figure 8: Test Setup for ATN Application Layer Trials.

For the dialogue establishment and data communication trials two Router/End systems were used for the establishment and release of dialogues as well as to send and receive CPDLC messages.

The used Router/End Systems did not automatically store the times of the dialogue establishment and release events. The times of all related user inputs and observations were recorded separately while the test was performed. To ease this recording a dedicated timer software was used which recorded the times of requesting a dialogue, the arrival of the dialogue request at the remote end system and for the termination of a dialogue. When a test event occurred the test operator had to press a key and the related time was stored in a log-file. The log-file could directly be evaluated by the PES spreadsheet software.

The input of messages was performed with the CPDLC Trials Application HCI. It was required to select and send particular messages. The time stamping of the sent and received messages was performed by the FITAMS trials software itself at the sending and receiving side, respectively. At each side of the communication channel the time-stamps were stored in a log-file together with the messages. The operator had to input one test message after the other and send it by activating a send button. After a while the message appeared at the other end of the ATN communication channel. The send and receive times were stored in the log-files together with the messages.

The log-file data was evaluated by the CODECAT PES.

4.4 Description of the CODECAT Trials Environment

4.4.1 CODECAT DLTE Fundamental Capabilities (DLTE)

The CODECAT DLTE was specially designed for the purpose of performing the comparative data link trials providing the following capabilities:

1. Bi-directional support of different data link interfaces like: AMSS, Mode S and NEAN
2. Fully autonomous operation allowing to perform a large number of test events without user intervention
3. Control by script-files containing each individual stimulus as well as 'Wait'-statements. Tests can thus flexibly be prepared in any required manner.
4. High sending data rates can be set up in order to drive the investigated data link into saturation. This allows to determine the available maximum user data bit-rate.
5. The sending data or packet rate can also be set to a lower level thus preventing to overload the data link during data transmission trials.
6. Time-stamped sending and receiving events of packets are stored in log-files.
7. A precise common time reference is implemented in the CODECAT DLTE by radio clocks.

Due to the similarities of the test activities for the individual data links it was appropriate to split the DLTE equipment functions into two major portions:

- **A Test Execution Kernel** which processes the script-file, generates the log-files and controls the overall test progress for all data links in the same manner

- **Dedicated Interfaces** which allow to access the particular data link. Almost any other data link interface can be added without touching the kernel.

This separation isolates the general testing capabilities from the actual interfacing functions. Figure 9 shows the overall software architecture of the CODECAT DLTE.

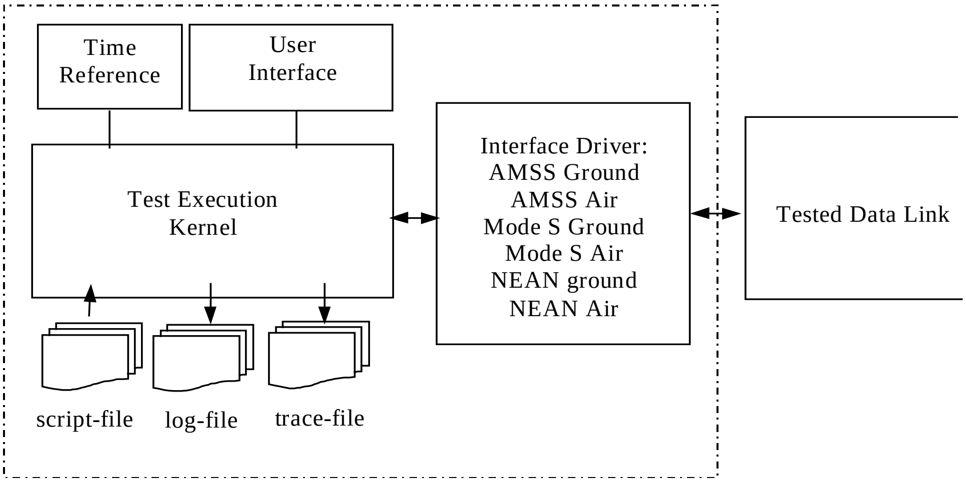

Figure 9: Architecture of the CODECAT DLTE Software

The Test Execution Kernel is the central element of the DLTE software. It controls the entire testing process. Two different modes (active and passive) cope with the different roles of the DLTE in the test setup.

In ***active mode*** the Test Execution Kernel actively controls the test. It sends the test stimuli stored in the script-file. It also processes received test events. Sent stimuli and received events are time-stamped and stored in log-files.

In ***passive mode*** the Test Execution Kernel only reacts to received events. It accepts the events from the data link interface and stores them in the log-file together with time-stamps.

The DLTE supports the following data link interfaces:

1. the ISO 8208 / ISO 7776 HDLC interface to Datex-P (AMSS subnetwork ground access).
2. the ISO 8208 / ISO 7776 HDLC interface to the T-GDLP (Mode S subnetwork ground access)
3. the ISO 8208 / Williamsburg interface to the SDU (AMSS Subnetwork air access)
4. the ISO 8208 / Williamsburg interface to the T-ADLP (Mode S Subnetwork air access)
5. the V.24 interface to the NEAN Local Server (NEAN data link ground access)
6. the V.24 interface to the NEAN Transponder (NEAN data link air access)

The interfaces are based on dedicated interface boards as well as communication software.

The DLTE software was developed for Intel Pentium II and above PCs with at least 64MB of RAM. Each DLTE hosts a radio clock card. The DLTE used at the airborne side also incorporates an ARINC 429 interface card while the DLTE used on the ground hosts an X.25 (ISO 8208) interface card. The DLTE software executes in the SUN Solaris 2.6 operating system.

4.5 Pre-Processing and Evaluation Software (PES)

4.5.1 Overview

The two log-files generated by the DLTE or the FITAMS CPDLC End Systems store the events recorded during the tests accompanied by time-stamps. The further evaluation is performed by the CODECAT PES. In order to obtain specific results like the data transmission latency the log-files needed to be pre-processed e.g. to derive the related raw latency times before they could be further evaluated. Based on these raw results, statistical information was deduced and graphs were generated to visualise the results by means of spreadsheet software. In the case of the CPDLC Dialogue Establishment, the log-file generated by the FITAMS CPDLC application can be processed by means of spreadsheet software without any pre-processing in advance.

The entire test result evaluation chain is depicted in Figure 10.

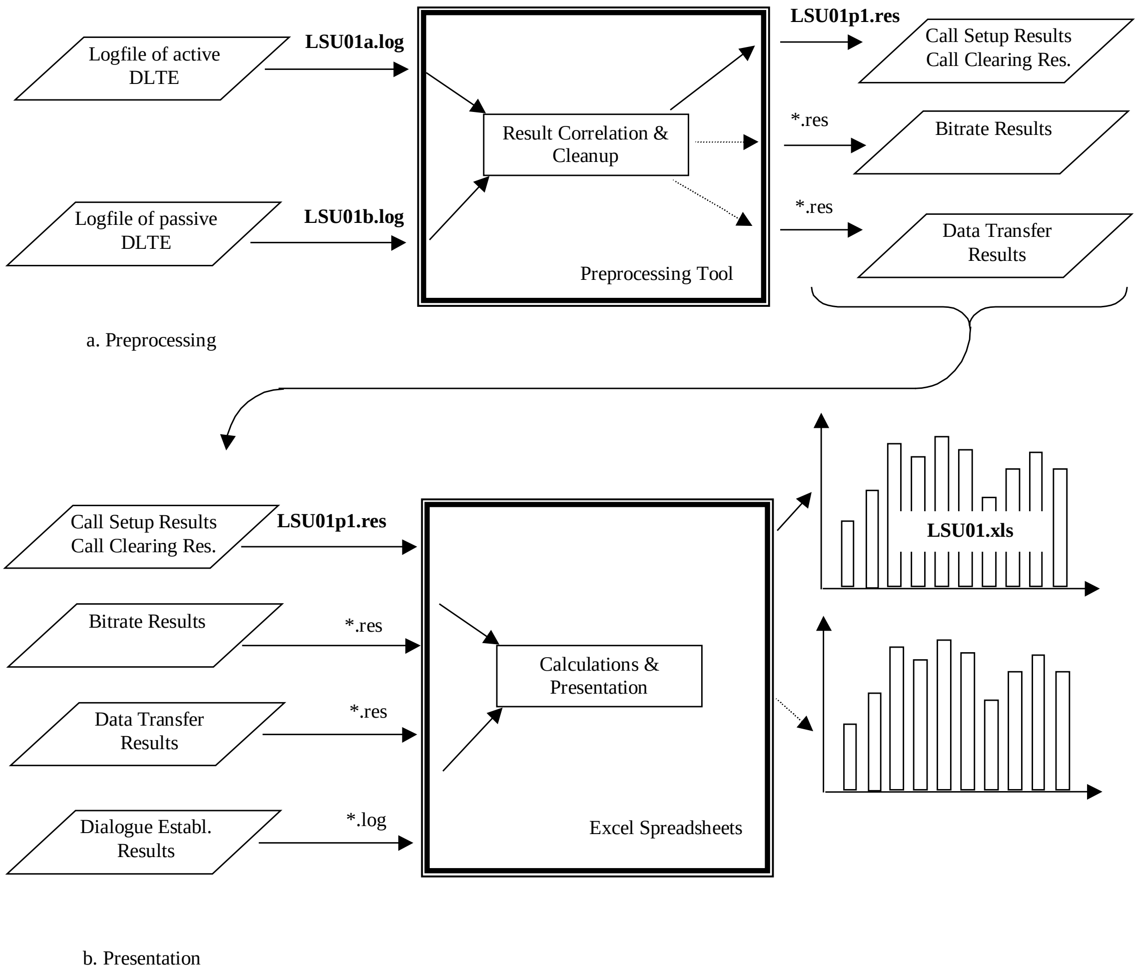

Figure 10: Overview over the CODECAT PES evaluation chain

4.5.2 PES Pre-processing

The first evaluation step shown in Figure 10 is the pre-processing. The pre-processing is performed by a dedicated software tool as part of the CODECAT PES, which can read and interpret the raw data log-files generated by the DLTE or the CPDLC End Systems.

A sample log-file as generated by the DLTE is shown below:

```
[Testinfo]
Testmode      = ...
scriptfilename   = ...
Script repetitions = ...
Data rate      = ...
Log-filename    = ...
Tracefilename   = ...
Interface     = ...
StartDate     = ...
StartTime     = ...
Timebasestatus   = ...

[Logstart]
09:16:23:044 R CallReq[]
09:16:23:066 S CallAcc[]
09:16:26:466 R Message[01A]
09:16:29:000 R Message[01B]
09:16:31:477 R Message[01C]
09:16:33:977 R Message[01D]
09:16:36:466 R Message[01E]
09:16:39:000 R Message[01AABCDEFGHI]
09:16:41:588 R Message[01BABCDEFGHI]
........
........
13:33:29:000 R ClearReq[]
13:33:29:500 S ClearConf[]

[Logend]
EndDate     = ...
EndTime     = ...
Timebasestatus = ...
Termination   = ...
```

For each experiment performed with the DLTEs a set of two log-files is generated, one at the sending and one at the receiving end of the data link. The log-file generated by the active DLTE is referred to as the 'active' log-file while the log-file recorded by the passive DLTE is referred to as the 'passive' log-file.

To obtain specific results like the data transmission latency these log-files are loaded by the PES pre-processing software. The pre-processing software reads the individual data records of the active and passive (DLTE) log-file and correlates the received packets with the related sent packets. After this the chosen pre-processing is applied. The pre-processing consists of one of the following options dependent on the objective of the experiment to be evaluated:

1. extraction of the times for sending and receiving of call establishment and call clearing packets,
2. extraction of the bit rates measured at the receiving end of the data link in data transmission experiments,
3. extraction of the data transmission latency times, the number of lost or corrupted packets.

The PES pre-processing software generates a result file which contains all information required for the final calculations and presentation by the spreadsheet software.

Result files can be read by the PES spreadsheet software.

4.5.3 Evaluation Diagram Presentation

The evaluation and presentation of the results is performed by a number of dedicated spreadsheets, which combine and analyse the data statistically dependent on the objectives of the tests. The results of the calculations are presented in a number of different diagrams as can be seen below. The following general types of diagrams are used in the evaluation of the results. A brief description is given below the diagram.

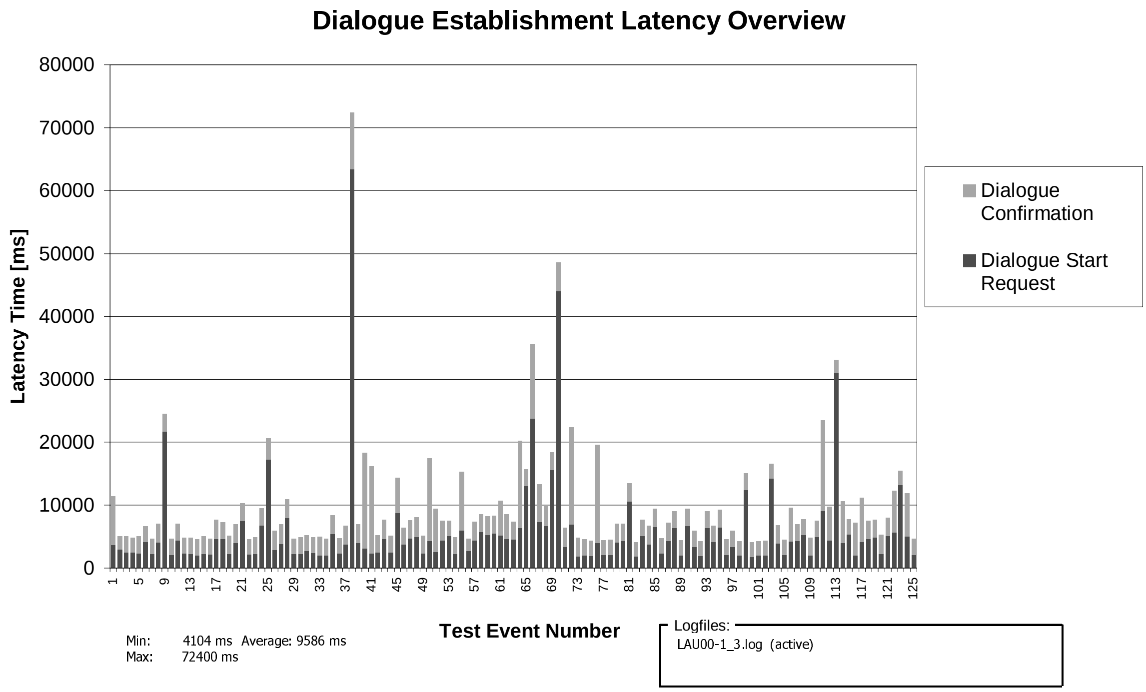

Figure 11: Dialogue Establishment or Call Setup Latency presentation (Example)

Figure 11 shows as an example the values of the Dialogue Establishment (Call Setup or CPDLC-start Service) Latencies per test event. The lower values (red/dark grey) show the times per individual test event for the Dialogue Request (Call Request or CPDLC-start Request) Latency while the upper values (orange/light grey) represent the Dialogue Confirmation (Call Confirmation or CPDLC-start Confirmation). The entire duration of Dialogue Establishment is the sum of the upper and the lower values.

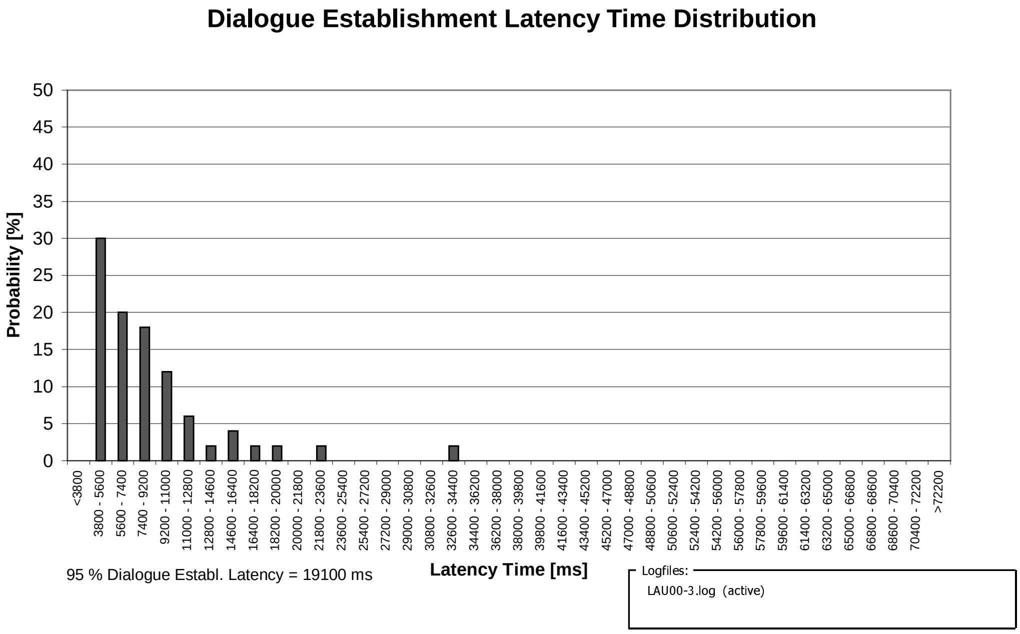

Figure 12: Latency Time Distributions (Example)

Figure 12 shows an example distribution of result values over 40 latency interval classes. The class boundaries are shown on the x-axis. The probability that results fell into a particular class is provided as the percentage out of all events. The sum of all probabilities shown therefore yields 100 %. In addition to the individual values shown in the diagram a 95% value is indicated. The value presented represents the latency boundary which is not exceeded by 95 % of the events.

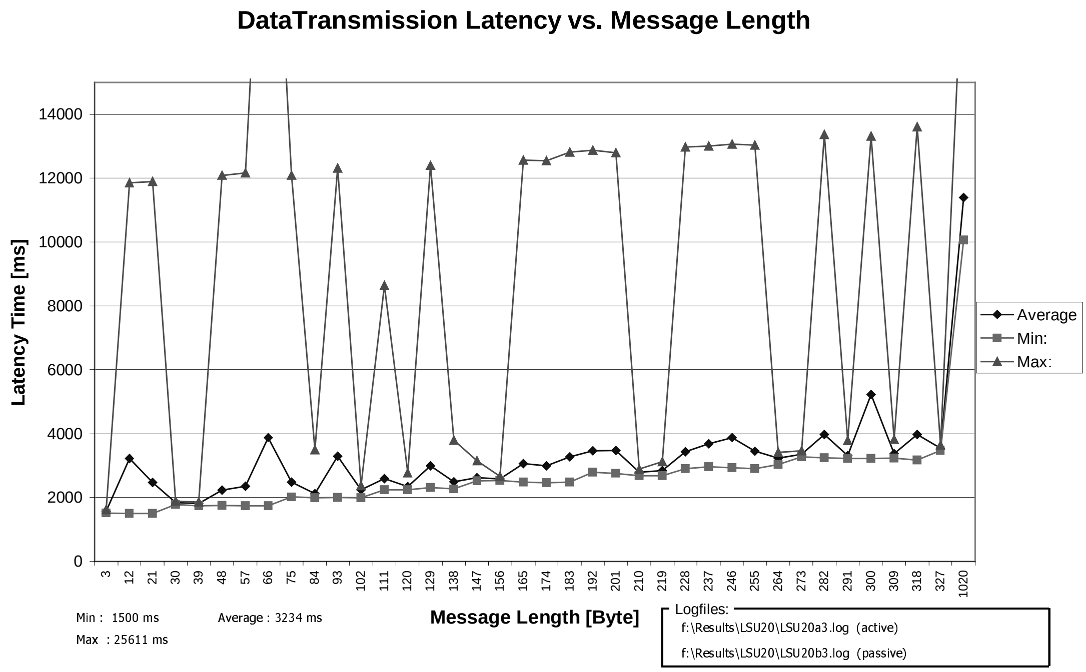

Figure 13: Latency Time vs. Message Length (Example)

Figure 13 indicates as another example for each used message length the related minimum, average and maximum values of the latency time derived from the test results. Additionally the overall minimum, average and maximum determined from all test events is displayed.

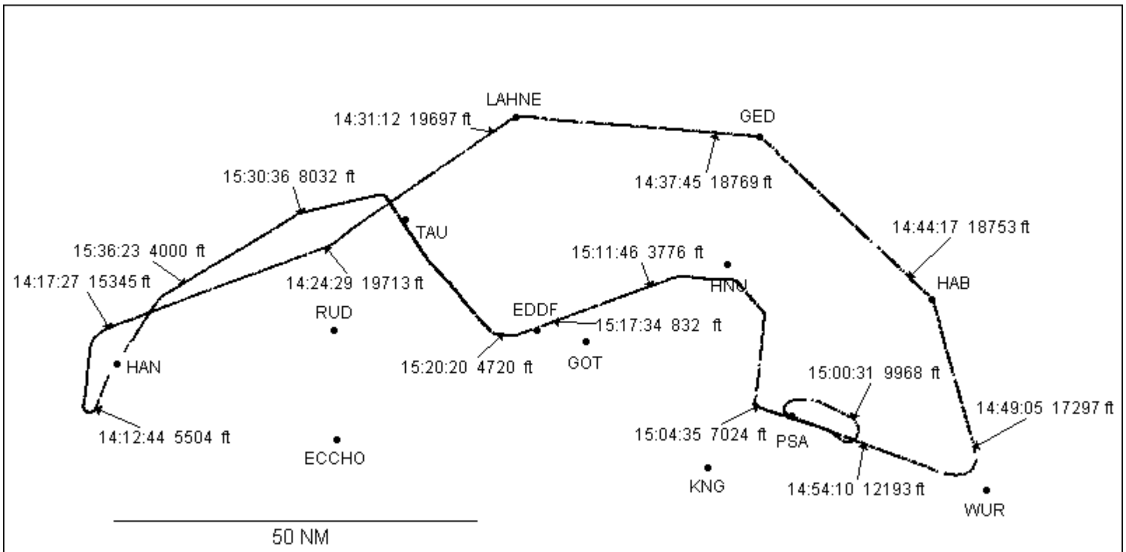

Figure 14: Example Flight Track (x/y)

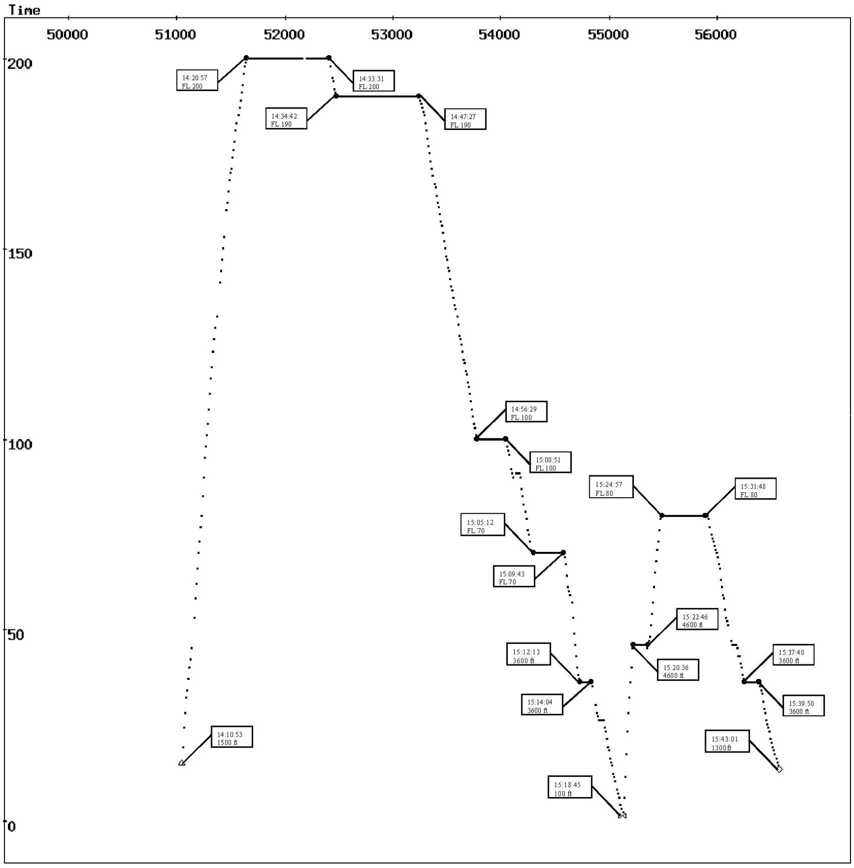

Figure 15: Example Flight Track (altitude)

Figure 14 and Figure 15 show an example flight track of one of the test flights (recorded during the flight). From the indicated UTC times the progress of the flight can be deduced. Together with the times also the altitudes at selected points are indicated in Figure 14. Several position fixes are also shown as reference points. The meaning of the most important fixpoints is :

HAN	Hahn (the base airport for the flight trials)
RUD	Rüdesheim
TAU	Taunus
GED	Gedern
WUR	Würzburg
EDDF	Frankfurt (Location of the NEAN ground station)
GOT	Götzenhain (Location of the experimental Mode S Radar)
LAHNE	Lahne
HAB	Hammelburg
PSA	Spessart

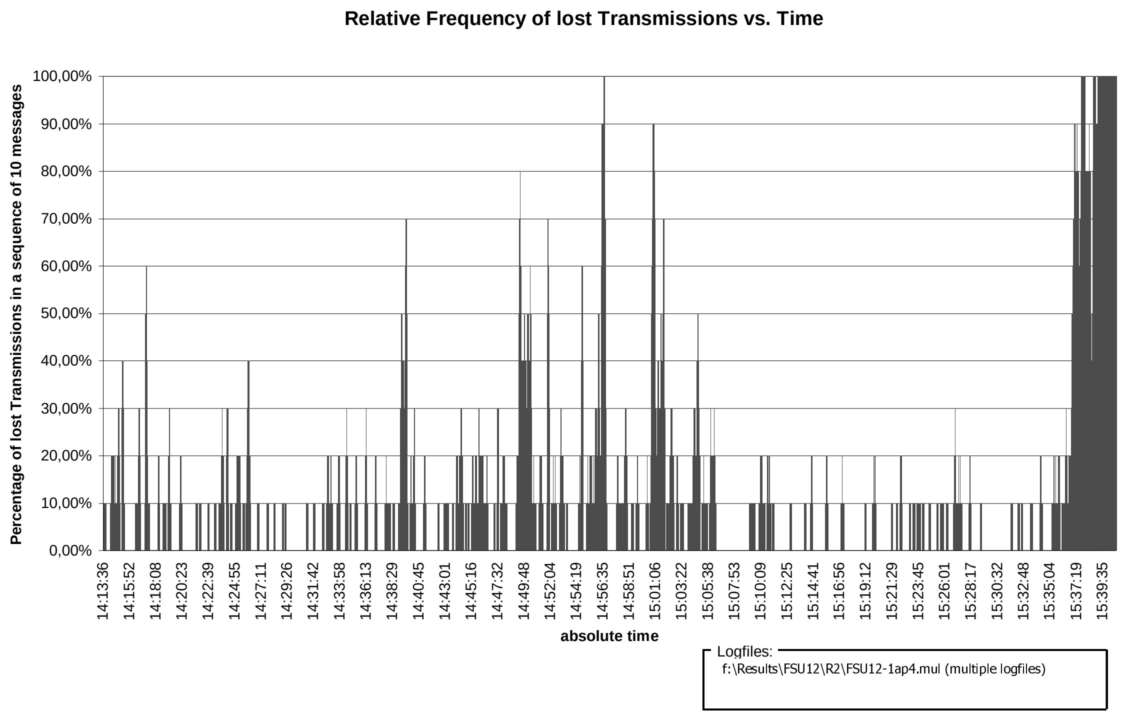

Figure 16: Percentage of lost Messages versus Time of Flight (Example)

Figure 16 shows as an example the relative percentage of lost messages versus the time *t* of flight indicated in UTC. To derive a measure for the strength of the losses a window of ten successive messages (see Figure 3) was taken in which the number of lost messages was counted. The number of lost message in that window was then expressed in percent of the 10 messages contained in the window. If one single message was lost in the window then the loss rate was calculated as 10 %. If ten successive messages were lost, then 100 % was derived.

The percentage of lost messages was calculated around each message entry in the logfiles (i.e. for one particular position of the lost message window). The related lost message window moves with the location of the message around which the percentage of lost messages is determined. It always includes the 5 previous and the 5 successive messages around the current message as shown in Figure 3.

As always ten consecutive messages are used to derive the lost message percentage one single lost message affects the result of 10 successive messages since it is located in ten successive lost message window positions as outlined in Figure 17.

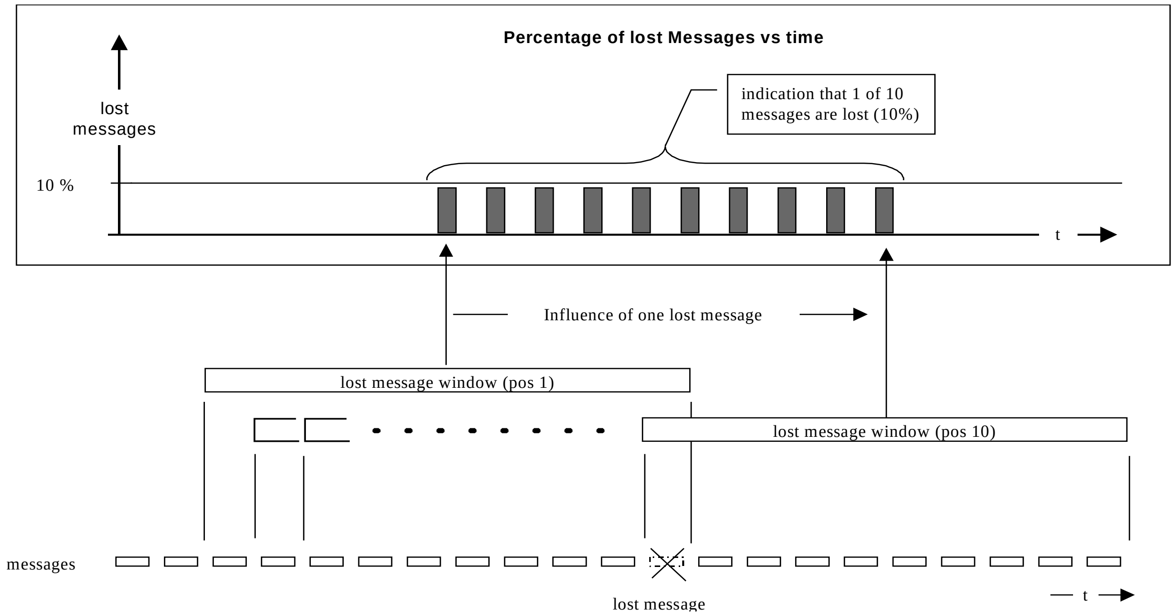

Figure 17: Determination of the Percentage of lost Messages by a Lost Message Window

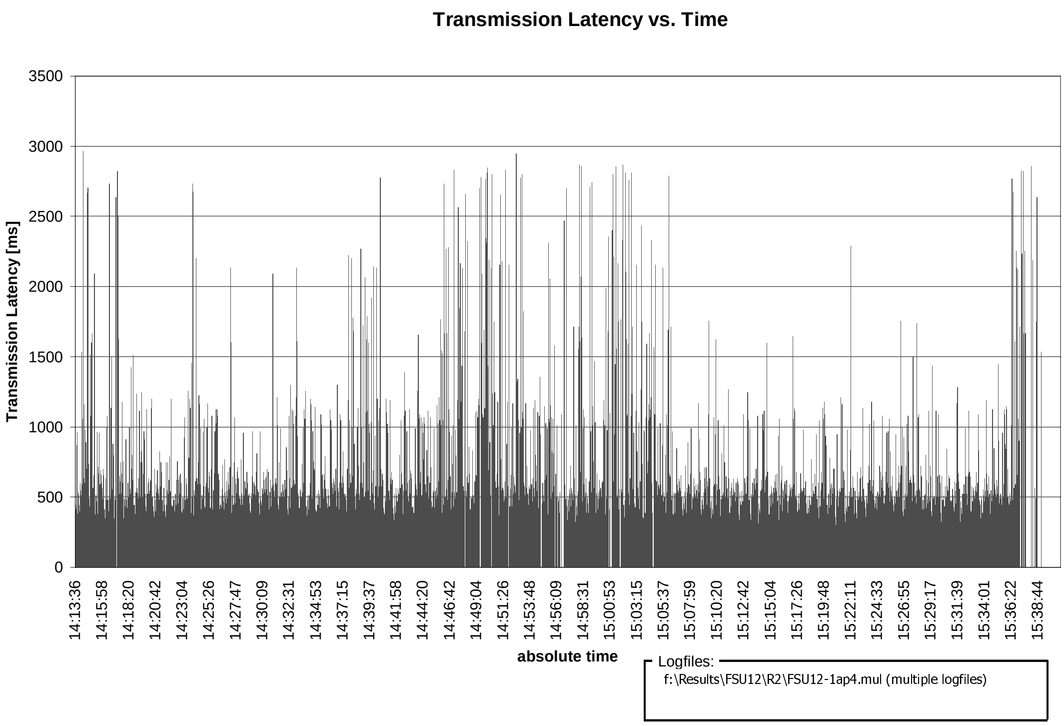

Figure 18: Transmission Latency versus Time of Flight (Example)

Figure 18 shows as example the transmission latencies of the individual messages measured versus the time of the flight. By means of this figure any dependencies can be determined from particular manoeuvres which could be obtained from the flight track.

4.6 Test Data

For the tests abstract test messages were used in the script-files. The scriptfiles were generated automatically prior to a test. The test data files are further described below.

4.6.1 Data Link Layer CallSetup - CallClearing Script-files

For data link CallSetup / CallClearing tests the script-files looked as follows:

```
[Scriptstart]
CallReq[]
ClearReq[]
Wait[35000]
[Scriptend]
```

The scriptfile was repeated by the DLTE 500 times, so that 500 call setup - call clearing cycles were performed. The DLTE waited after a Call Request until the Call accept was received. This ensures that the speed of the test was directly controlled by the speed of the data link and that only one SVC was open at a time. After each cycle a wait of 35 seconds was inserted so that the individual cycles were sufficiently separated.

4.6.2 Application Layer Data Transmission Script-files

The messages used for the tests had different lengths, so that the impact of the message length on the data link parameters could be determined. At application layer the scriptfiles for data transmission looked as follows:

```
[Script]
Message[1AB]
Message[2ABCDE]
Message[3ABCDEFGH]
Message[4ABCDEFGHIJK]
Message[5ABCDEFGHIJKLMN]
Message[6ABCDEFGHIJKLMNOPQ]
[Scriptend]
```

The scriptfile was repeated by the test operator 20 times so that 120 message were exchanged in total.

4.6.3 Data Link Layer Data Transmission

On data link layer extensive trials were performed. For the correlation of received and sent messages it was required that all exchanged messages had a different content to enable distinction of all messages from each other. The messages were generated by an automatic message generator, which created messages between 3 and 327 characters in steps of 9 characters plus one message of 1020 characters. These messages correspond to message lengths between 3 and 1020 bytes. The investigated properties of the data links are independent from the message content so that artificial messages were used as test data rather than real messages. The artificial messages had significant advantages in the evaluation process over real messages.

The transfer rate determination measurement required that always at least two consecutive messages had the same length, so that no transmission latency time differences of different length messages could influence the transfer rate determination. An optimum solution to this would have been to send all messages of one length in sequence. However, then the message length would change during the test (i.e at the beginning messages of 3 bytes would have been sent and at the end only messages of 1020 bytes). If the investigated data link had non-stationary parameters, then temporary fluctuations could have been attributed to length changes and might thus have lead to a wrong interpretation of the results. In order to avoid this, the different message lengths were distributed equally over the entire measurement interval.

A data link test script-file contained 20 cycles each starting with a Call_Request and ending with a Clear_Request. Each of these cycles contained 38 different message lengths where always 5 messages of equal length appeared in sequence. In total 3800 messages were listed in the script-file.

All messages were built from capital ASCII characters appearing in sequence. To distinguish the messages of the different cycles from each other the first two characters represented the cycle number in hexadecimal notation. The 5 messages of equal length are further distinguished by the characters "A" (for the first message) and "B", "C", "D", "E" (for the consecutive messages) as the third character of the message. A typical data link layer scriptfile looked as follows:

```
[Script]
CallReq[]
Message[01A]
Message[01B]
Message[01C]
Message[01D]
Message[01E]
Message[01AABCDEFGHI]
Message[01BABCDEFGHI]
Message[01CABCDEFGHI]
Message[01DABCDEFGHI]
Message[01EABCDEFGHI]
...
ClearReq[]
CallReq[]
Message[02A]
Message[02B]
Message[02C]
Message[02D]
Message[02E]
Message[02AABCDEFGHI]
Message[02BABCDEFGHI]
Message[02CABCDEFGHI]
Message[02DABCDEFGHI]
Message[02EABCDEFGHI]
....
ClearReq[]
[Scriptend]
```

5 The investigated Data Link Configurations

This chapter describes in detail the data links which were incorporated into the data link test setup which had been described above (see chapter 4.2).

5.1 North European ADS-B Network (NEAN)

The NEAN data link configuration is shown in Figure 19. The actual data link configuration to be tested is shown in the dashed box.

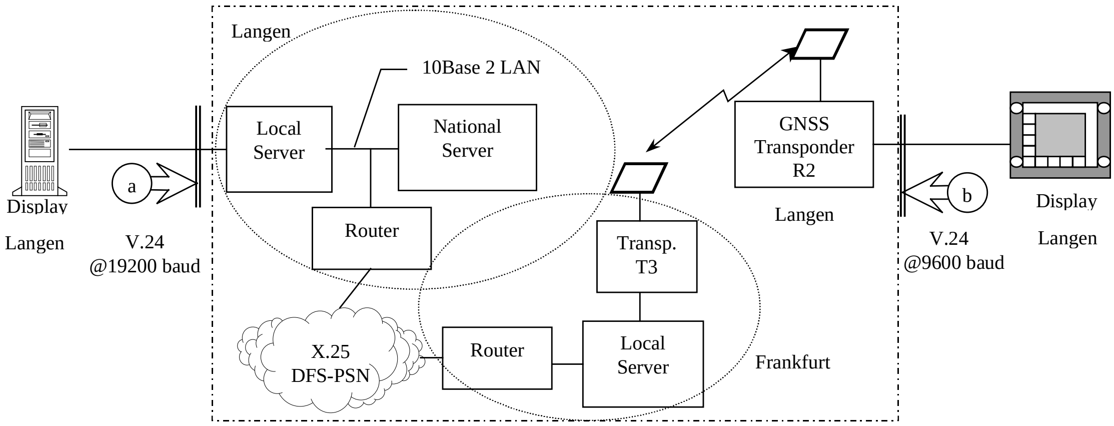

Figure 19: NEAN Data Link Configuration

The NEAN configuration was based on two different NEAN compatible transponders on the ground, one representing a ground and one an airborne transponder. The DLTEs were connected at points 'a' and 'b'. The 'airborne' DLTE was directly connected to the R2 transponder in Langen (interface 'b'). The ground DLTE was connected to the Local Server located in Langen (interface 'a') while the communication with the T3 transponder was accomplished via the DFS X.25 Packet Switching Network and another Local Server located in Frankfurt.

Both NEAN transponders had significant difficulties to handle an overload of input packets. They especially did not provide flow control mechanisms to throttle the packet rate down. It was therefore essential that the packet rate to which the transponders were exposed to did not exceed the transponder capabilities. On the airborne side this was easily possible since the 'airborne' DLTE was directly connected to the R2 transponder. On the ground side however the data packets first traversed through two computers and a packet switched network. This chain transports individual packets as dictated by the network properties and leads to situations where packets which had been sent at well defined time intervals by the ground DLTE arrive at the T3 transponder shortly after each other. In other words the equal distance of packets could not be ensured if the data was sent on the uplink.

5.1.1 Ground Interface "a" (NEAN gnd)

The ground interface of the NEAN data link is shown in Figure 20. The ground measurement interface to the NEAN data link is based on a dedicated NEAN message interface implemented by a V.24 electrical interface. It provides no flow control mechanisms.

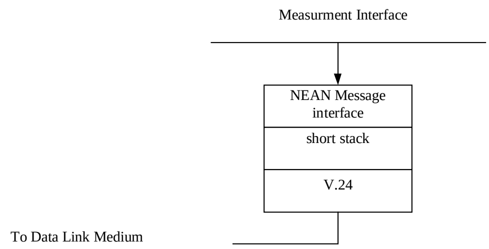

Figure 20: NEAN Ground Measurement Interface

5.1.2 Aircraft Interface "b" (NEAN air)

The NEAN aircraft interface is similar to the ground interface "a".

5.2 Mode S

Figure 21 shows the complete SSR Mode S subnetwork configuration used in the trials. The actual subnetwork configuration to be tested is shown in the dashed box.

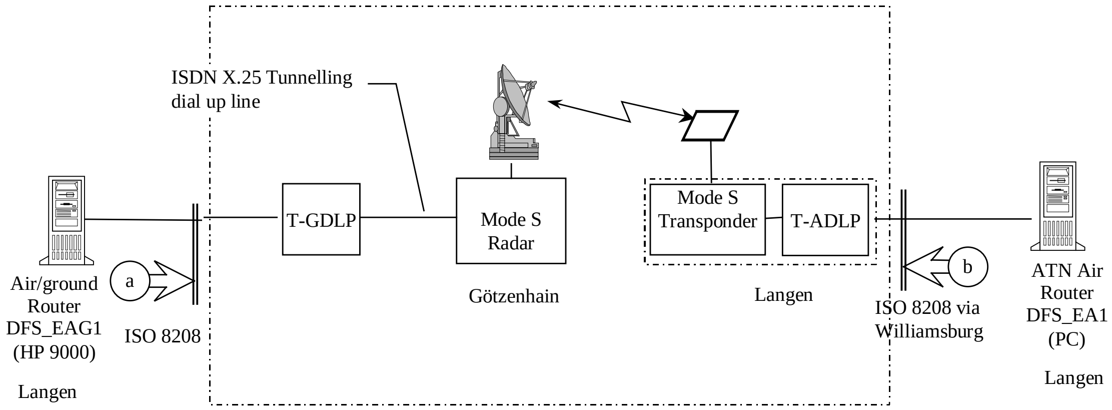

Figure 21: SSR Mode S Subnetwork

The involved components are the following:

1. T-GDLP
2. Mode S Radar
3. Mode S Transponder
4. T-ADLP

The detailed definition of the components for Mode S can be found in Attachment D. In contrast to the other data link systems, the Mode S radar, operating in a dense aircraft environment close to Frankfurt, has to deal simultaneously with both, surveillance interrogations with many aircraft, and data link messages to the transponder under test. Due to Mode S system design surveillance transactions take precedence over communication transactions. The experimental radar developed in early 1990 has a limited capacity and is only used for experimental Mode S data link trials. The radar was, build according to Mode S standards published in 1989 and upgraded to comply at least partially with Mode S Subnetwork standards published in 1993. In consequence, although Mode S data link traffic is exchanged only with one single transponder, the large number of Mode S targets in the Frankfurt area nevertheless demand a high activity of the radar, which therefore operates at its limits in terms of serving all targets with surveillance interrogations. The radar needs to communicate with the transponder via its rotating radar antenna. As the corresponding transponder antenna is located on the ground, the beam shaping of the radar antenna results in a non-typical (reduced) gain at which the transponder is seen by the radar.

The T-GDLP is the first prototype implementation complying to the Mode S SARPs but the software still contains some bugs, which occasionally caused problems.

The transponder is a certified avionics transponder developed for EUROCONTROL in 1980 with known limited data link capabilities. However, only one avionics manufacturer is offering a full data link capable .transponder, which was not available for the trials.

The T-ADLP is an experimental implementation complying to the Mode S SARPs, developed and validated for about 10 years. It was replaced for the flight trials by a prototype ADLP developed by NLR.

Both, T-ADLP and T-GDLP were developed by different manufacturers according to 1993 Mode S Subnetwork SARPs and upgraded later to comply with the latest SARPs version published in 1998. Nevertheless showed both implementations different shortcomings (cmp. [20]).

5.2.1 Ground Interface "a" (Mode S ISO gnd)

The ground interface of the SSR Mode S Subnetwork is shown in Figure 22. The ground measurement interface to SSR Mode S is the upper layer interface of the ISO 8208 protocol stack which is in this case based on LAPB.

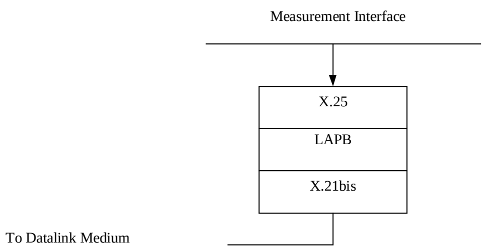

Figure 22: Mode S Ground Measurement Interface

5.2.2 Aircraft Interface "b" (Mode S ISO air)

The aircraft interface of Mode S is shown in Figure 23. The aircraft measurement interface to the Mode S is the upper layer interface of the ISO 8208 protocol stack which is in this case based on the Williamsburg and the ARINC 429 physical layer.

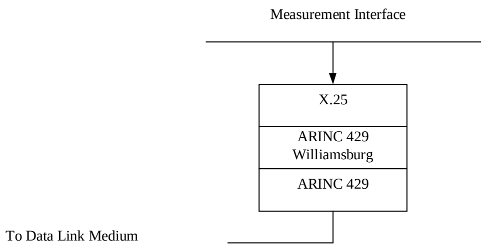

Figure 23: Mode S Aircraft Measurement Interface

5.3 Aeronautical Mobile Satellite Subnetwork (AMSS)

Figure 24 and Figure 25 show the investigated configuration of the Aeronautical Mobile Satellite Subnetwork in its environment. The actual subnetwork configuration tested is shown in the dashed boxes.

Unfortunately all uplink Call_Request messages of the Inmarsat satellite services in Germany were by default routed to the Raisting GES of the German PTT which is not capable to support the Data 3 service as required by the trials. The AMSS DATA 3 services therefore had to be routed to the ground station in Aussaguel (France). This however was not supported by the German PTT Datex-P PSN at all. Uplink trials therefore had to be performed by a direct access to the French Transpac system which allowed this routing. This was facilitated by a dialed line to the EUROCONTROL Experimental Centre (EEC) in Bretigny where Transpac was accessed (see Figure 24). The downlink trials could be performed with the X.25 access of the German PTT since downlink services were routed from Aussaguel to Langen via the Transpac and Datex-P PSNs as shown in Figure 25.

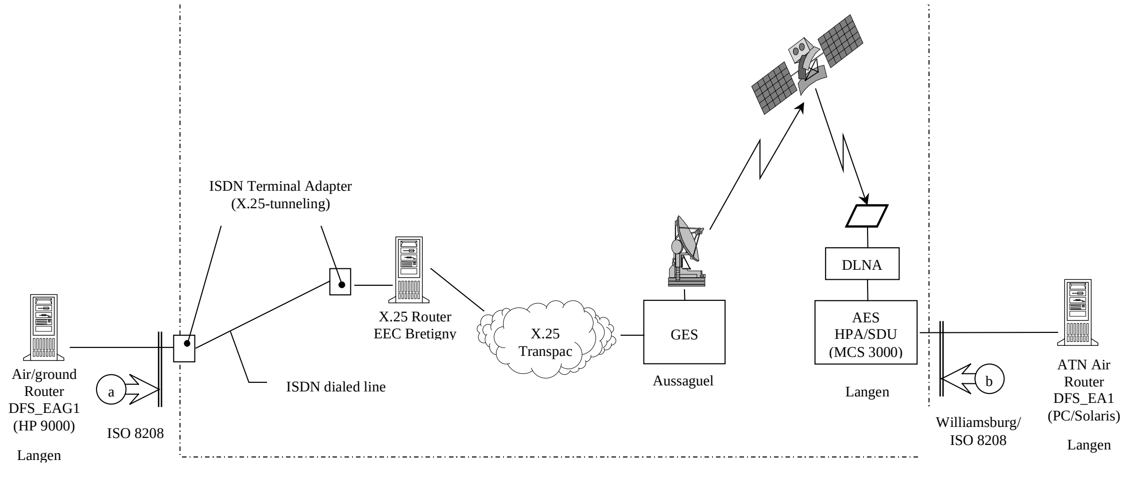

Figure 24: Aeronautical Mobile Satellite-Subnetwork (Uplink)

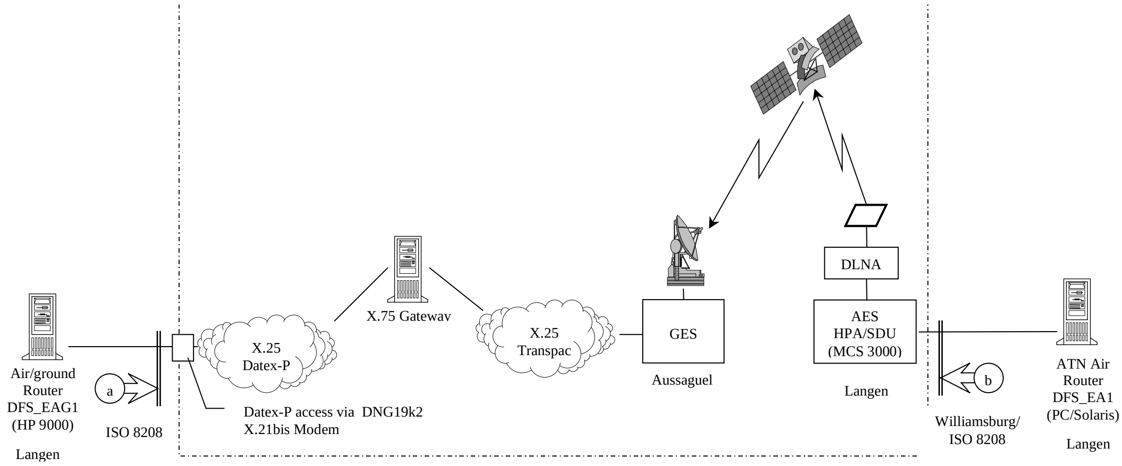

Figure 25: Aeronautical Mobile Satellite-Subnetwork (downlink)

The ground portion of the AMSS is constituted by the GES, which communicates with the Aircraft Earth Station (AES) via a satellite. The AMSS provides an ISO 8208 interface at the SNACPs. The GES is located in Aussaguel, France. Downlink messages are transferred via the French Transpac Packet Switched Network (PSN), an X.75 Gateway and the German X.25 Datex-P PSN. Uplink messages had to be sent to the EEC in Bretigny via a dialed line where the access to the French Transpac was possible. From there the data was routed to the GES and via the satellite to the AES.

The definition of the component data of the AMSS can be found in Attachment D.

5.3.1 Ground Interface "a" (AMSS gnd)

The ground interface of AMSS is similar to that of the Mode S ground access.

5.3.2 Aircraft Interface "b" (AMSS air)

The AMSS ISO 8208 aircraft interface is similar to the Mode S aircraft interface.

6 Experiments and Results

6.1 General

The experiments were performed in two major groups:

1. Laboratory experiments to obtain more fundamental results
2. Flight trials to investigate any additional effect attributable to the in-flight operation of the data link

The tests had the following objectives:

1. To determine the Call Setup and the Call Clearing Latencies
2. To determine the available transfer rate per connection
3. To determine the Data transmission Latency, lost messages, corruptions, etc.

The laboratory trials were performed with the real data link facilities. The relatively low operational cost of the laboratory trials allowed to obtain large amounts of result data. During the flight trials additional results were obtained with smaller sets of experiment data but in real flight. These tests thus complemented the laboratory trials. The technical overall Objectives of the tests are described in the following paragraphs.

6.1.1 Call Setup and Call Clearing

The Call Setup experiments were performed in the following manner. A Call Request was transmitted by the active DLTE, and traversed through the transmission medium and after a short time interval arrived at the remote DLTE. The remote test tool responded to the Call_Request and replied by a Call_Accept, which was after a further transmission latency received by the sending test tool. After the Call_Confirmation packet was received a Clear_Request was issued which again traversed across the data link medium. The local DCE immediately responded by a Clear_Confirmation even before the related Clear_Request had reached the remote test tool. The remote test tool replied to the Clear_Request immediately with a Clear_Confirmation that was not transmitted across the data link medium.

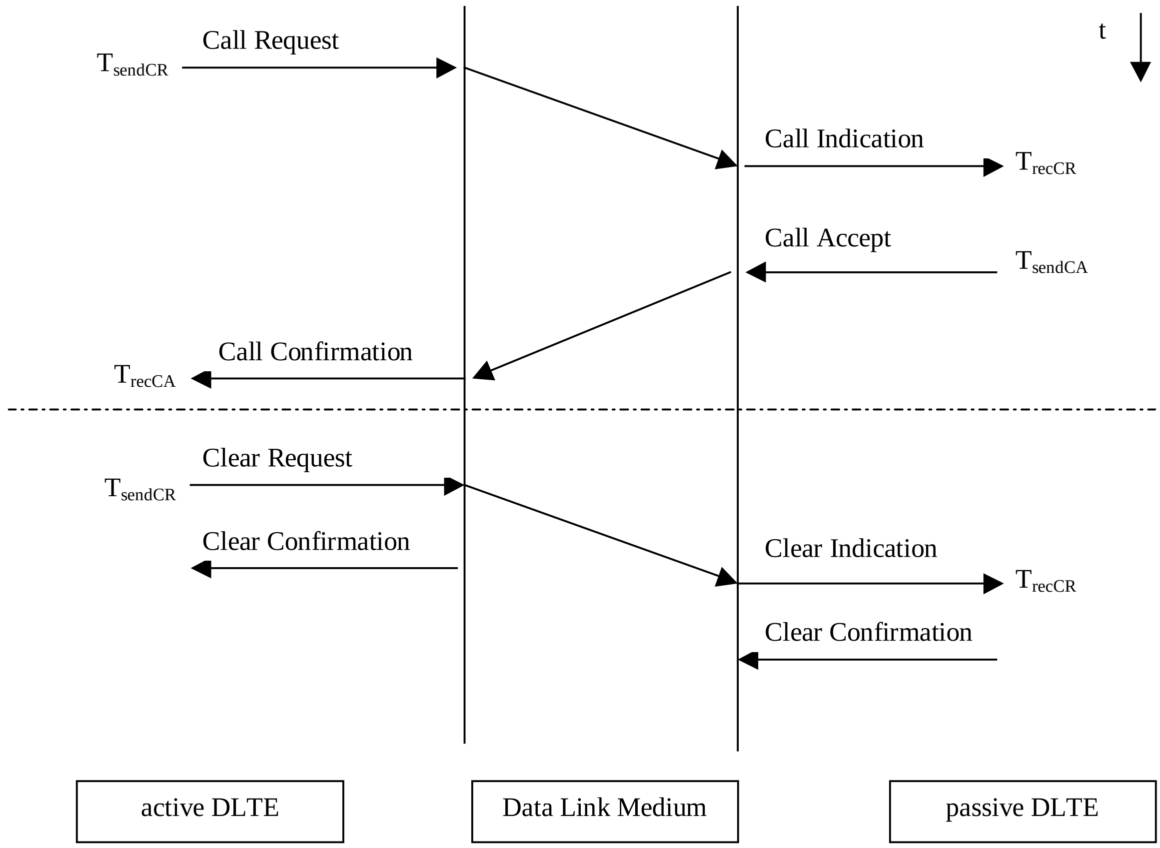

Figure 26: Test principle of the call setup / call clearing experiments

The event times of the Call_Request sending, the Call_Indication reception, the Clear_Request sending and the Clear_Indication reception are recorded by the test tools and stored in the log-files for later evaluation.

6.1.2 Determination of the available Transfer rate

It was also of interest to obtain the available user data transfer rate of the data link medium. For this purpose the test tool was set up to send a larger data rate than the data link could support. By this the data link became the limiting element in the transmission chain. The received data rate was determined which is the transfer rate available to one user. The related test principle is shown in Figure 27.

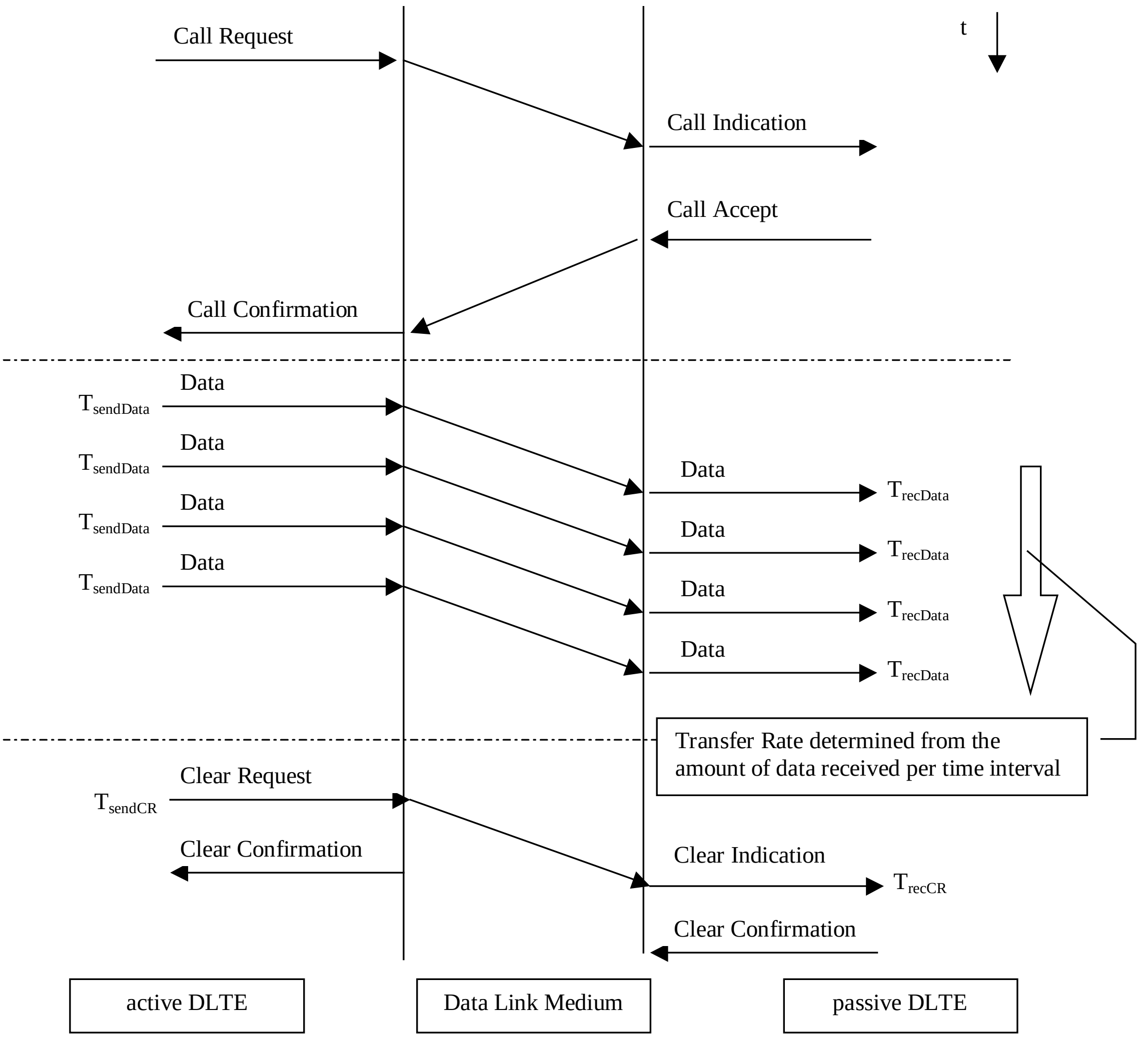

Figure 27: Test Principle of the Transfer Rate Trials

In first instance the data link was considered as a black box which transmitted bits until its capacity is reached. As a consequence it was assumed that the transfer rate was more or less constant irrespective of the packet length used. Initial tests however unveiled that this approach led to unrealistic results. The reason for that was as follows:

The investigated data links did not have the behaviour of a bandwidth limited continuous transmission channel. Instead the nature of the data links to transfer the data in packets rather than as bit-streams became significantly visible.

If a constant sending bitrate was imposed, then short messages had to be transmitted at high message rates while longer messages were to be transferred at low message rates. This had the following consequences:

1. The NEAN data link had significant difficulties when the bitrate was held constant since short packets were received within too short intervals by the NEAN transponders, causing an overload condition of the transponders. This led to severe data losses as the transponders were totally overloaded by the short message rates: The NEAN transponder is able to handle up to 3 messages per second. The reason

for that is found in the software code where the polling of the serial interface is limited. There is neither an overload processing foreseen in the transponder software code nor a flow control between the transponder and the connected DTE. If more messages are being delivered the transponder goes into uncontrolled operation where messages are being skipped.
The limitation to 3 messages per second is also necessary because of the required duty cycles of the experimental radio. If more than 3 messages per second are being delivered to the transponder the radio would be damaged.

2. In case of the AMSS downlink experiments the problem arose that queues built up in case of short messages arriving at a too high packet rate so that longer messages which had to be transferred by a different protocol (and higher priority) overtook the short messages still stored in message queues. This in turn caused resets of the virtual circuits so that the trials stopped frequently.
3. During the Mode S experiments the T-GDLP showed problems on high data rates. The XON/XOFF flow control initiated by the radar caused the T-GDLP to crash while a REJECT packet was sent in XOFF state. This bug didn’t appear earlier in the component development due to the focus on CPDLC message exchange. It has been reported and is currently under investigation by EUROCONTROL, but hasn’t been removed yet.

One solution to solve the problems is to significantly lower the sending bitrate so that no problems are caused any more in case of short messages. However, then the sending bitrate would be significantly lower than the data link could provide for longer packets so that an unrealistically low transfer rate was determined for the longer packets.

The final solution to the problems was to send the test data at a constant packet rate rather than a constant bitrate. The DLTEs were modified accordingly so that they allowed to send at a predefined packet interval. The packet rate still had to be set higher than the channel packet rate in order to make the channel the limiting element in the transfer rate trials. Aside of the transfer rate also the available packet rate was determined from the trials results.

6.1.3 Determination of the Data Transmission parameters

After a call setup phase a large number of messages was transferred across the data link medium while the transmission and reception events were recorded The test principle is shown in Figure 28

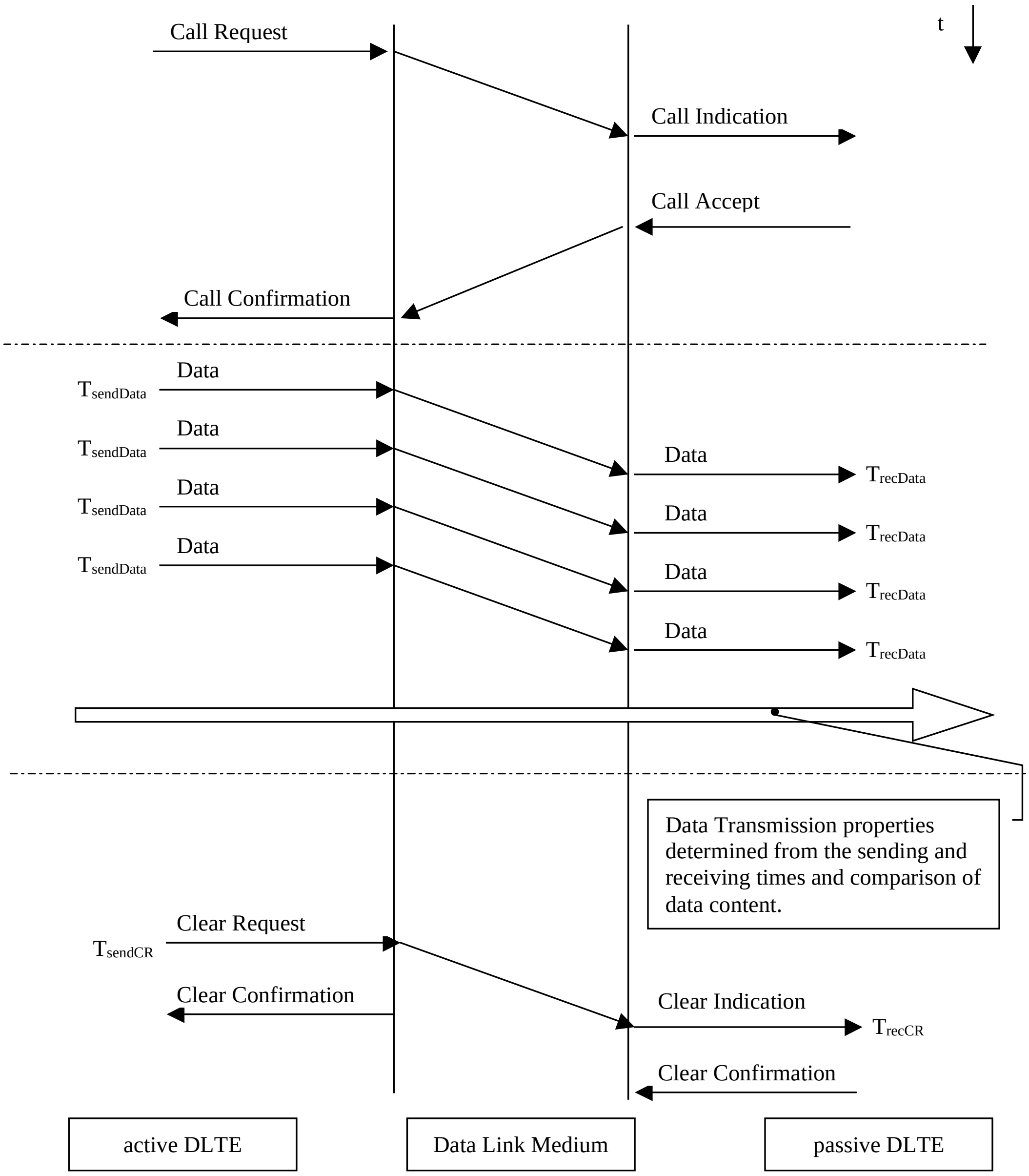

Figure 28: Test Principle of the Data Transmission Trials

The NEAN data link suffered most from too high packet rates. Even at low packet rates a certain amount of losses was observed.

In the AMSS data link it was discovered that the transmission latencies increased while messages of the same length were sent. This was attributed to the building up of queues. The result of this effect was that the data transmission latency was not only a function of the message length but also significantly dependent on the rate at which packets were sent to the system. It was therefore significantly important that the sending packet rate was set that low that no queues could build up.

In case of high packet rates the Mode S data link showed the same problem as described in 6.1.2 (T-GDLP crash). In addition to that, queues within the radar and T-GDLP have the same effect on the link as on AMSS.

To avoid this effect the sending packet rate needed to be set sufficiently low so that no queues could build up. The data transmission trials were performed at about 80% of the packet rate determined during the transfer rate determination experiment. According to /21/ new Mode S data link implementations should not suffer from the limitations mentioned above.

6.2 Laboratory Trials

6.2.1 Application Layer Trials

6.2.1.1 Objectives

The comparative data link investigations focused on two different views. One was the view of the user which is in particular turned on the used data link applications like the Controller to Pilot Data Link Communication (CPDLC), Automatic Dependant Surveillance (ADS) or the Flight Information Services (FIS) (see this chapter “Application Layer Trials”) and second a more or less technical view which gives its special attention to the different characteristics of the data link technologies (see chapter 6.2.2 “Data Link Layer Trials”).

The overall objective of the Application layer communication trials was to determine the end-to-end communication parameters and properties of a particular ATN communication application. For this purpose CPDLC was chosen. Aside of obtaining the fundamental parameters of this communication application it was also interesting to determine the difference of the parameters at application layer and at data link layer.

For the application layer the following parameters were determined:

1. The Dialogue Establishment Latency (CPDLC-start Service),
2. The Dialogue Release Latency (CPDLC-end Service),
3. The Data Transmission Latency (CPDLC-message Service)

The following three sequence diagrams shall illustrate the course of CPDLC communication events:

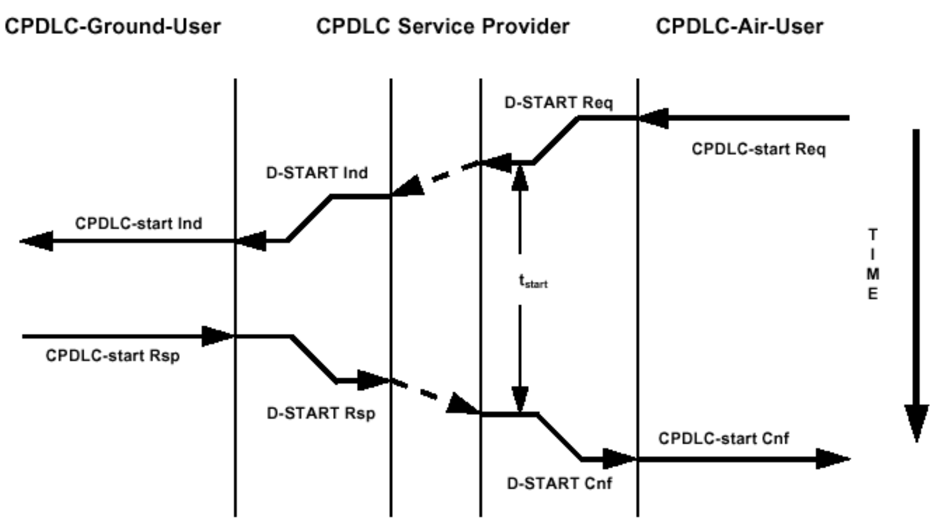

Figure 29: Sequence Diagram for CPDLC-start Service/Air Initiated

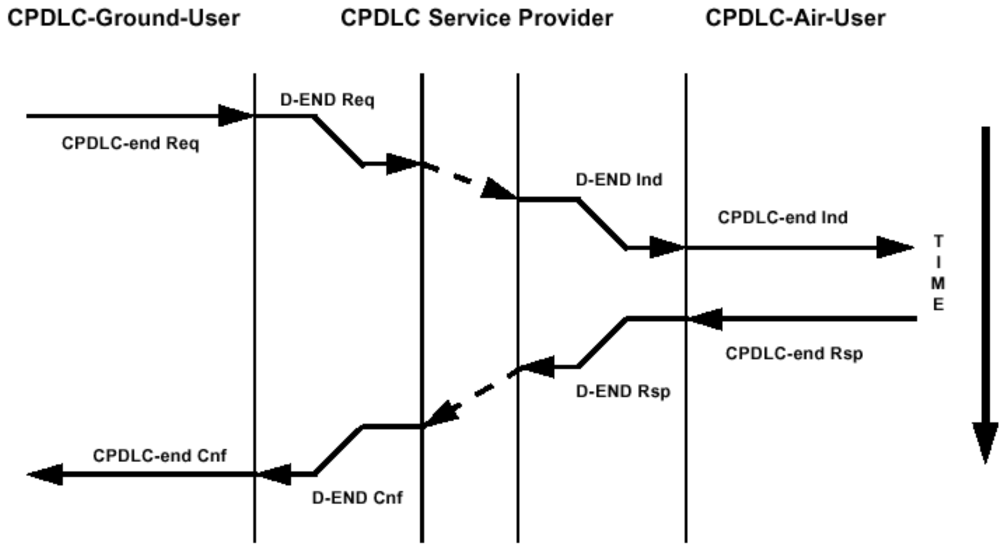

Figure 30: Sequence Diagram for CPDLC-end Service

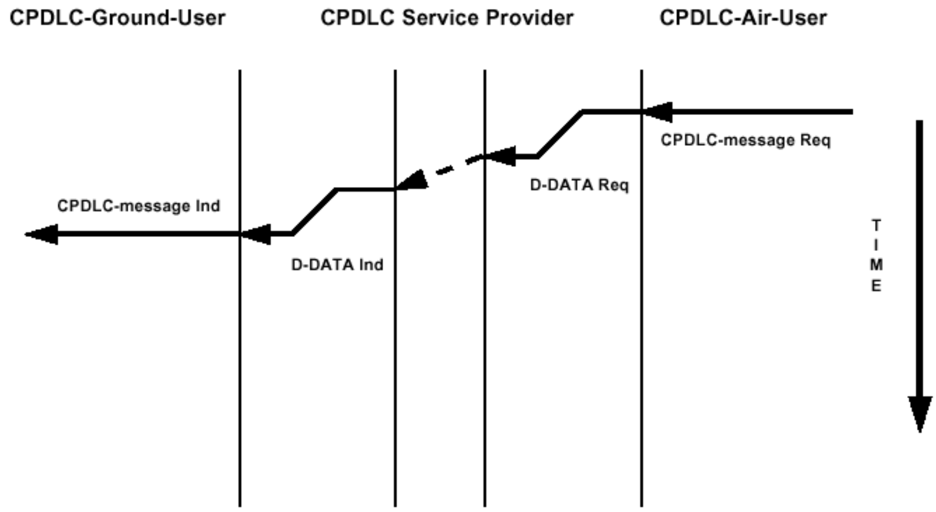

Figure 31: Sequence Diagram for CPDLC-message Service/Air Initiated

The CPDLC application is connection oriented and requires the setup of a so-called Dialogue prior to the data transmission. To understand how long it takes to set up a Dialogue the Dialogue Establishment latency experiments were performed in which a Dialogue was established and released 150 times by the Human Control Interface (HCI). The resulting Dialogue Establishment and Release latencies were measured and evaluated.

Different situations may be identified as pre-dialogue establishment status:

1. The target aircraft is not "acquired" by the data link medium (i.e. no join event has been generated so far)

2. The target is already acquired by the data link medium and an ATN connection exists on the transport layer.

It is assumed that a data link equipped aircraft will normally operate in an ATN environment, which means that a sensor (Mode S radar, VDL ground station, satellite) is in permanent contact with the aircraft and will thus have logged on to the ATN system (case 2). This means that an X.25 Switched Virtual Circuit (SVC) between an airborne ATN router and a ground ATN router does already exist. Under these circumstances a Dialogue Establishment Request can directly be forwarded to the target and no establishment of an ATN transport connection is required in advance.

The trials were performed with experimental implementations of the FITAMS CPDLC application (developed by EUROCONTROL). This implementation of the CPDLC application provides an HCI only and thus could not be used in automatic tests with large numbers of test events. Therefore dialogues were established and terminated manually. The timing was measured by a separate software tool accepting user inputs when a test event occurred.

In this connection it must be noted that FITAMS CPDLC doesn't behave as recommended in the ATN SARPs in the case of CPDLC-end Service, because the application doesn't wait for a CPDLC-end Confirmation. An information-window which says “Connection Released” is generated immediately by the ground user interface after the “Release”-button is pushed. This means that the CPDLC dialogue release latencies in this report are the time between the generation of a CPDLC-end Request and the receipt of the CPDLC-end Indication. This sequence is illustrated in Figure 32:

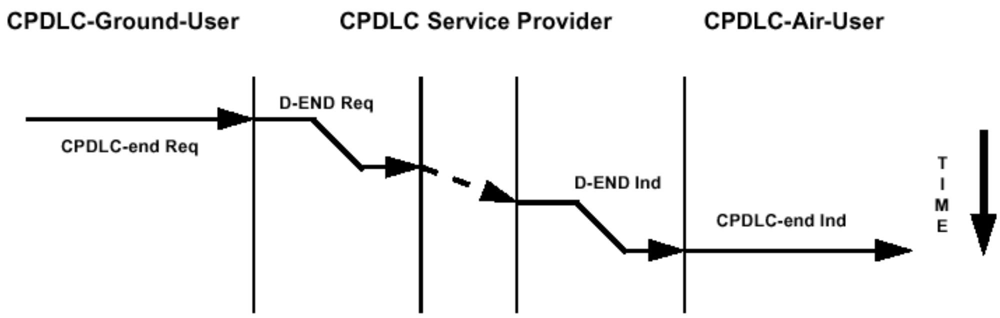

Figure 32: Sequence Diagram for CPDLC-end Service in the case of FITAMS CPDLC

The data transmission trials, of course, required the previous establishment of a Dialogue. In contrast to the Dialogue Establishment trials described above the messages were logged with time-stamps and recorded in log-files. Several messages with ascending length between 3 to 18 characters in steps of 3 were transmitted as free-text messages from one CPDLC end system to a remote one. In the tests 60 messages in total were exchanged.

The general approach of the tests was identical for AMSS and for Mode S, respectively. The two different data links were interfaced at ISO/IEC 8208 network layer.

6.2.1.2 CPDLC over AMSS

6.2.1.2.1 CPDLC Dialogue Establishment Latencies via AMSS

The test results shown in this section address the CPDLC Application Layer Dialogue Establishment and Release Latencies when using the AMSS subnetwork for transport.

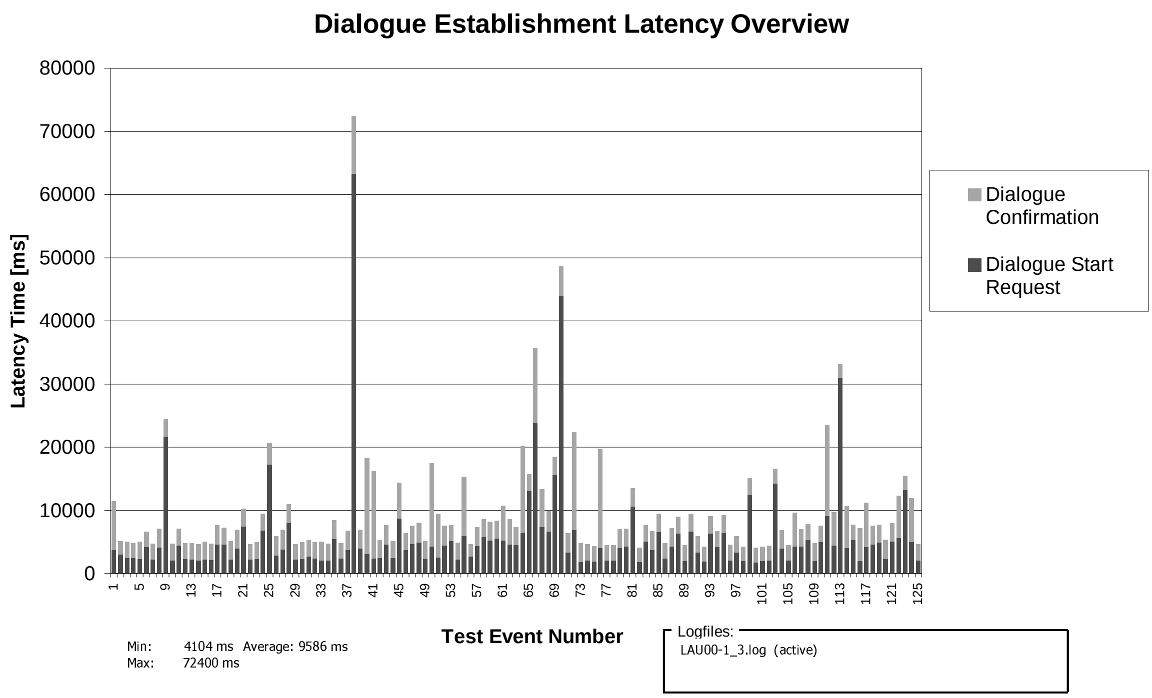

Figure 33: Measured Latency in CPDLC Dialogue Establishment (AMSS ground-initiated dialogue)

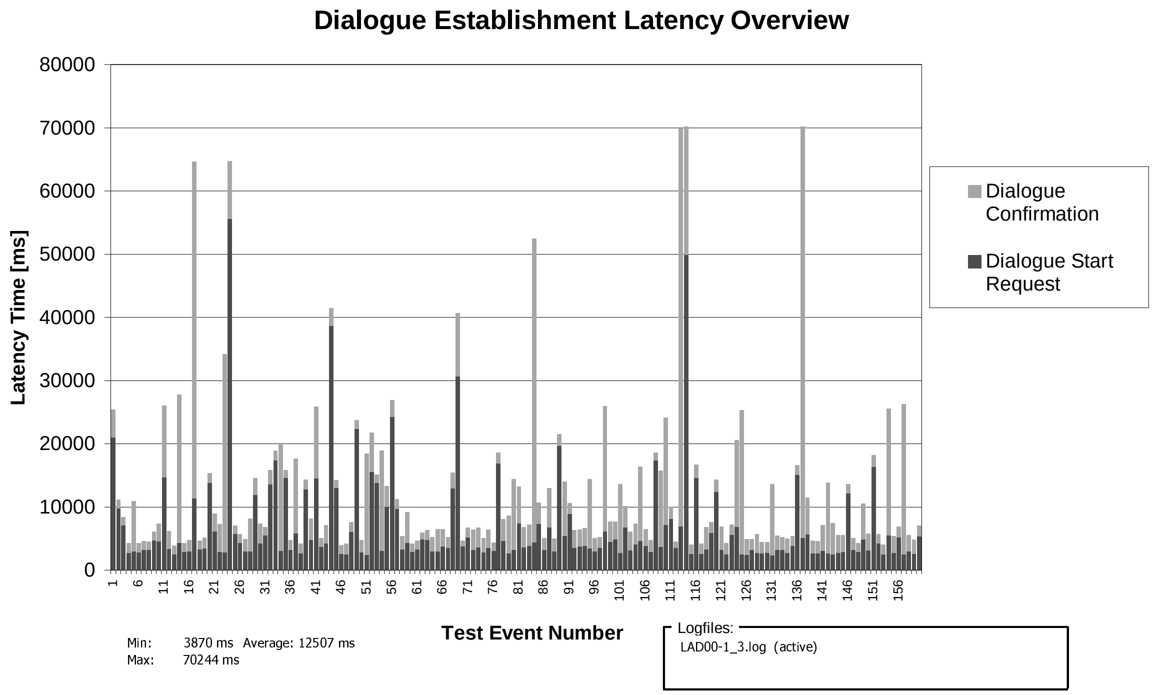

Figure 34: Measured Latency in CPDLC Dialogue Establishment (AMSS air-initiated dialogue)

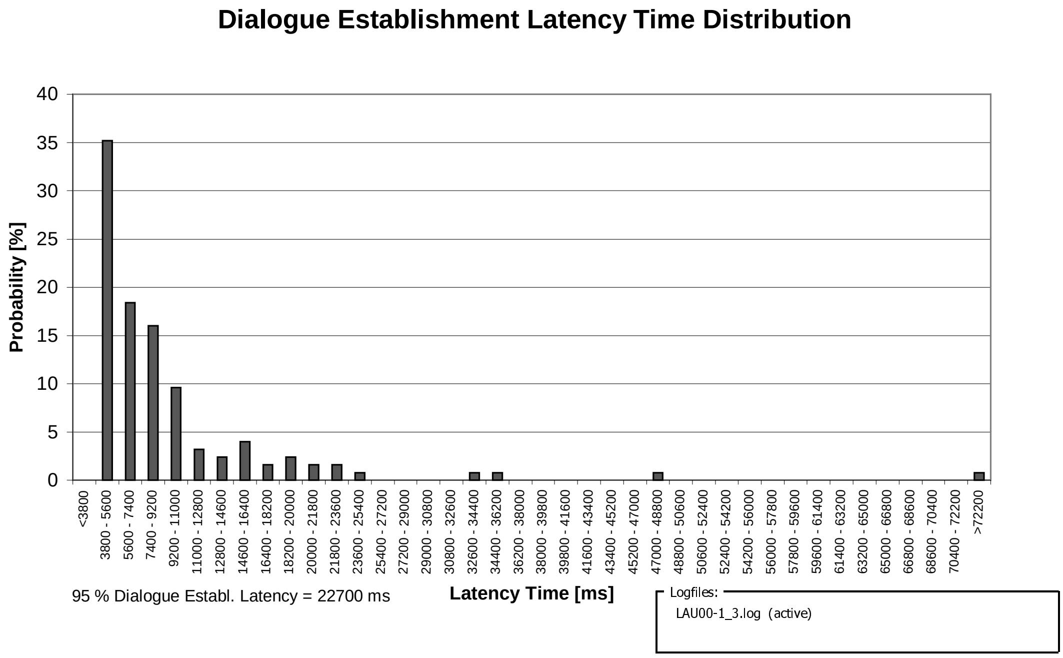

Figure 35: CPDLC Dialogue Establishment Latency Distribution (AMSS ground-initiated dialogue)

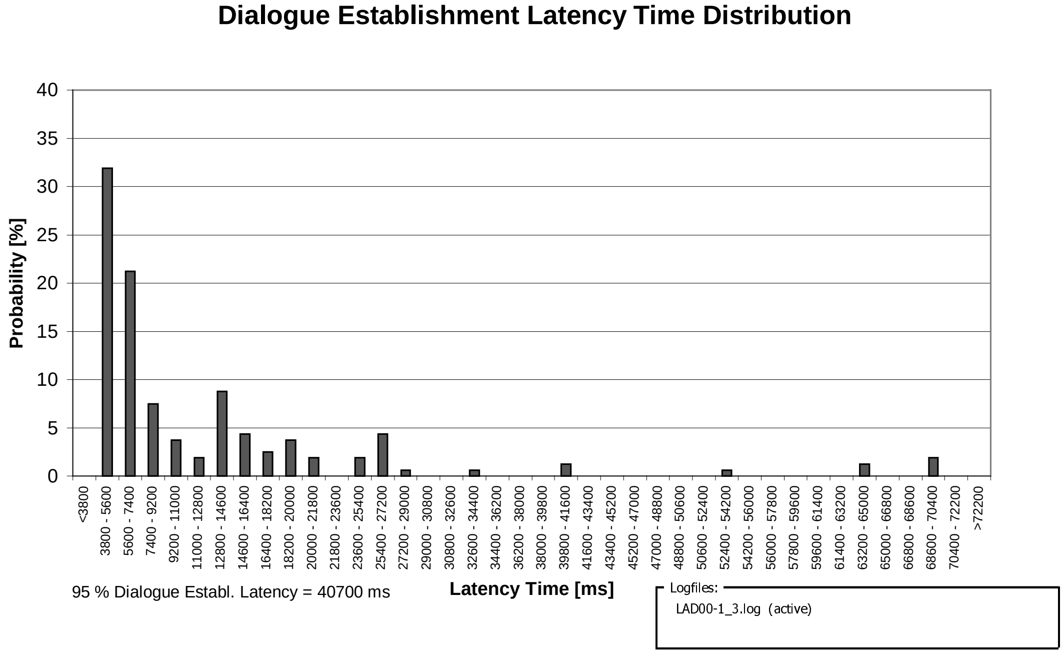

Figure 36: CPDLC Dialogue Establishment Latency Distribution (AMSS air-initiated dialogue)

Observations	data link: AMSS		
direction: ground-initiated air-initiated	experiment ID: LAU00 LAD00	figures: Figure 33- Figure 36	objectives: CPDLC Dialogue Establishment & Release Latencies

1 Significant fluctuations of the Dialogue Establishment Latency can be observed during a test-run.

Further analysis confirmed three explanations that can be given:

- Crossing protocol information units influenced the transmission behaviour;
- the R-Channel which is used for the downlink of packets smaller 33 bytes is not very reliable. More than 10 % of transmissions require retransmissions;
- measurements performed on different days reveal a dependency of the data transmission latency and the traffic load.

Detailed information on these analysis are attached in appendix C.2.

2 The average Dialogue Establishment Latency is about 30% higher in the air-initiated case than in the ground-initiated case.

An analyse of the communication sequence of an air-initiated CPDLC dialogue establishment and a ground-initiated dialogue release (see appendix C.2) reveal the following PDU exchange:

- air-initiated case:
  1 PDU via the P-channel (TP4 Call_Confirmation)
  1 PDU via the R-channel (TP4 Call_Request)
- ground-initiated case:
  1 PDU via the P-channel (TP4 Call_Request)
  1 PDU via the R-channel (TP4 Call_Confirmation)

A TP4 Acknowledge which confirmed the correct transmission of the Call_Confirmation didn't influence the Dialogue Establishment Latency time, because this PDU isn't visible to the CPDLC user.
It was therefore expected that there shouldn't be different latency times for an air-initiated or ground-initiated CPDLC Dialogue, because the number and size of exchanged packets is in both cases more or less similar. The reason for the observed difference was obviously a different traffic load when the tests were performed. This assumption was corroborated by an additional air-initiated test performed in March 2000. The results are very similar to the results achieved for the ground-initiated experiment due to an obvious lower traffic load.

3 The uplinked dialogue request delay in the case of ground-initiated dialogue establishment (Figure 33) has an average of 5696 ms whereas the downlinked dialogue confirmation takes 3891 ms in average.
For the air-initiated case (Figure 34), the uplinked dialogue confirmation is in a similar order as the uplinked dialogue request of the ground-initiated dialogue i.e. 5791 ms.
The difference of 30 % for the average Dialogue Establishment Latency (air-initiated case compared to ground-initiated case) is predominantly caused by the downlinked dialogue request which has an average of 6717 ms for the air-initiated

Observations	data link: AMSS		
direction: ground-initiated air-initiated	experiment ID: LAU00 LAD00	figures: Figure 33- Figure 36	objectives: CPDLC Dialogue Establishment & Release Latencies

case.

This means that the observed difference between the air- and ground-initiated case is caused by a discontinuous transmission behaviour of the R-channel which changes between the different experiments, whereas the transmission behaviour of the P-channel was more or less constant.
The reason for this asymmetric behaviour of the uplink and downlink is most likely the different channel structure available in these directions and the way they are influenced by the traffic load.

Parameter		**Results**	
		Ground-initiated	**Air-initiated**
Total Dialogue Establishment Latency	min	4 104 ms	3 870 ms
	average	9 586 ms	12 507 ms
	95%	22 700 ms	40 700 ms
	max	72 400 ms	70 244 ms
Test Conditions			
Data 3 users logged on		1	1
Data 2 users logged on		88	88

Table 6: CPDLC Dialogue Establishment & Release Latencies (AMSS)

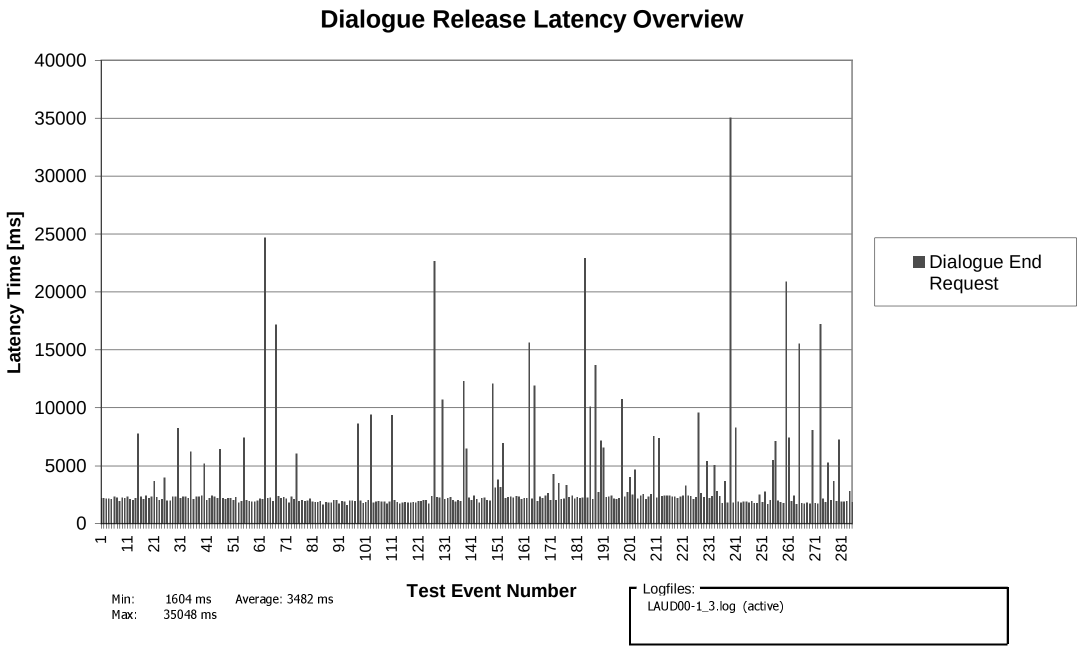

Figure 37: Measured Latency in CPDLC Dialogue Release (AMSS ground-initiated dialogue release)

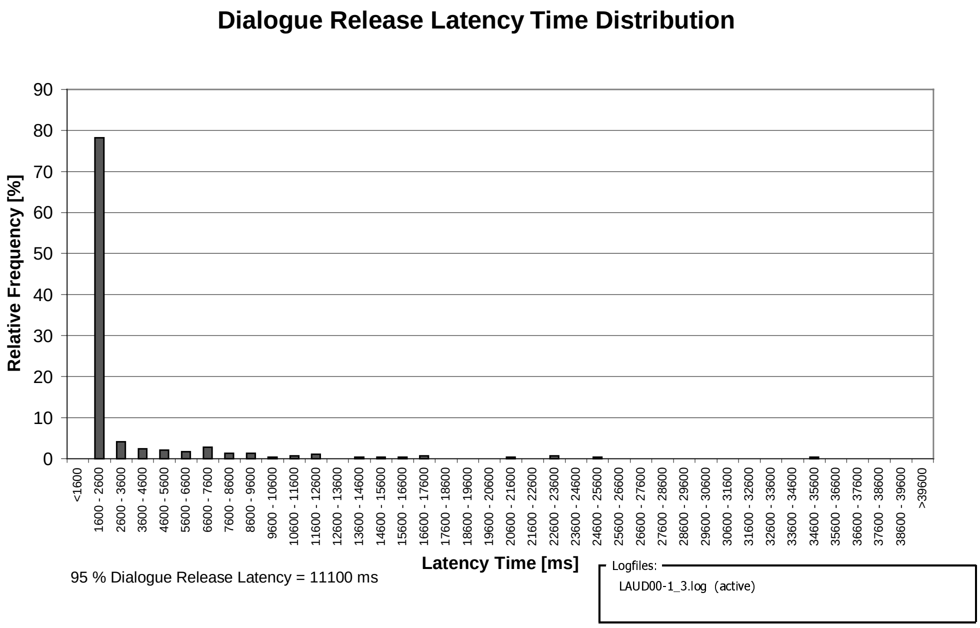

Figure 38: CPDLC Dialogue Release Latency Time Distribution (AMSS ground-initiated dialogue release)

Observations	data link: AMSS		
direction: ground-initiated air-initiated	experiment ID: LAU00 LAD00	figures: Figure 37 - Figure 38	objectives: CPDLC Dialogue Release Latency

1	Beside some few (i.e. 6 to 7) extreme deviations the measured Dialogue Release Time is almost constant. The majority (almost 80%) of the measured Dialogue Release Times are in the range of 1,6 to 2,5 seconds. This result is very promising as this measured one-way delay is more than acceptable for most (or even all) anticipated data link applications."
2	The average Dialogue Release Time is less than half of the average Dialogue Establishment Time. This is not surprising as the Dialogue Release involves an one-way transfer across the data link as compared to the two-way transfer for the Dialogue Establishment.

Parameter		**Results**
		Ground-initiated
Dialogue Release Latency	min	1 604 ms
	average	3 482 ms
	95%	11 100 ms
	max	35 048 ms
Test Conditions		
Data 3 users logged on		1
Data 2 users logged on		88

Table 7: CPDLC Dialogue Release Latency (AMSS)

6.2.1.2.2 CPDLC Data Transmission Latencies via AMSS

The test results shown in this section address the CPDLC Application Layer Data Transmission Latencies when using the AMSS subnetwork for transport.

In the case of data transmission latency tests, each type of packet (between 3 and 18 bytes) was transmitted 20 times. Due to this limited number of measurements, extremes have a high impact on the average.

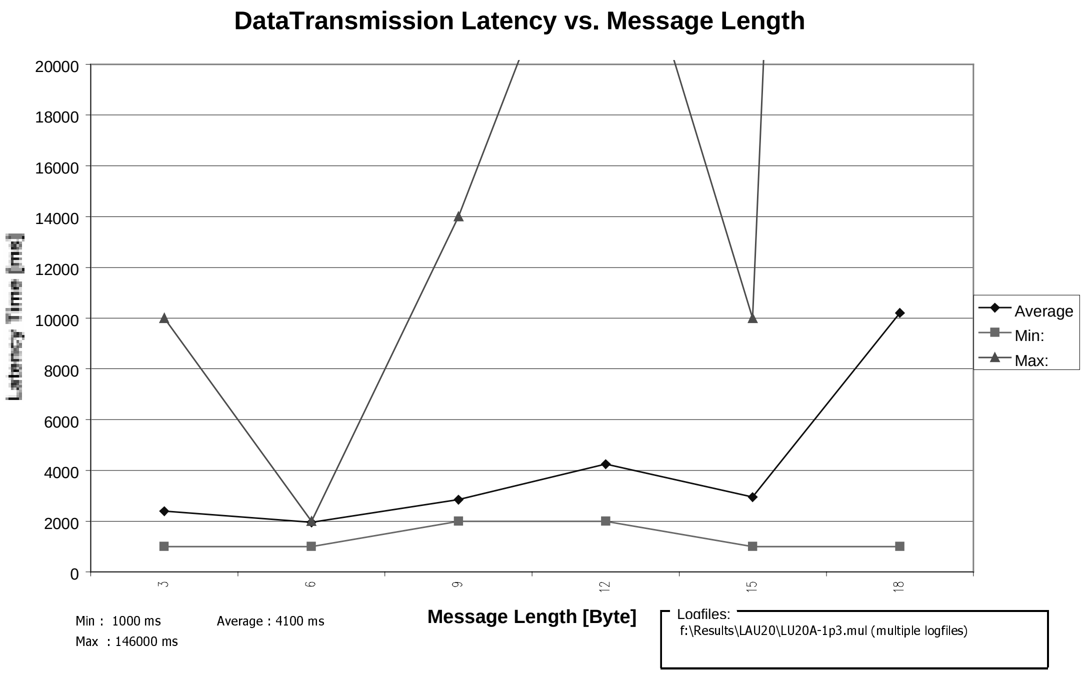

Figure 39: CPDLC Data Transmission Latency Time as a Function of the Message Length (AMSS uplink)

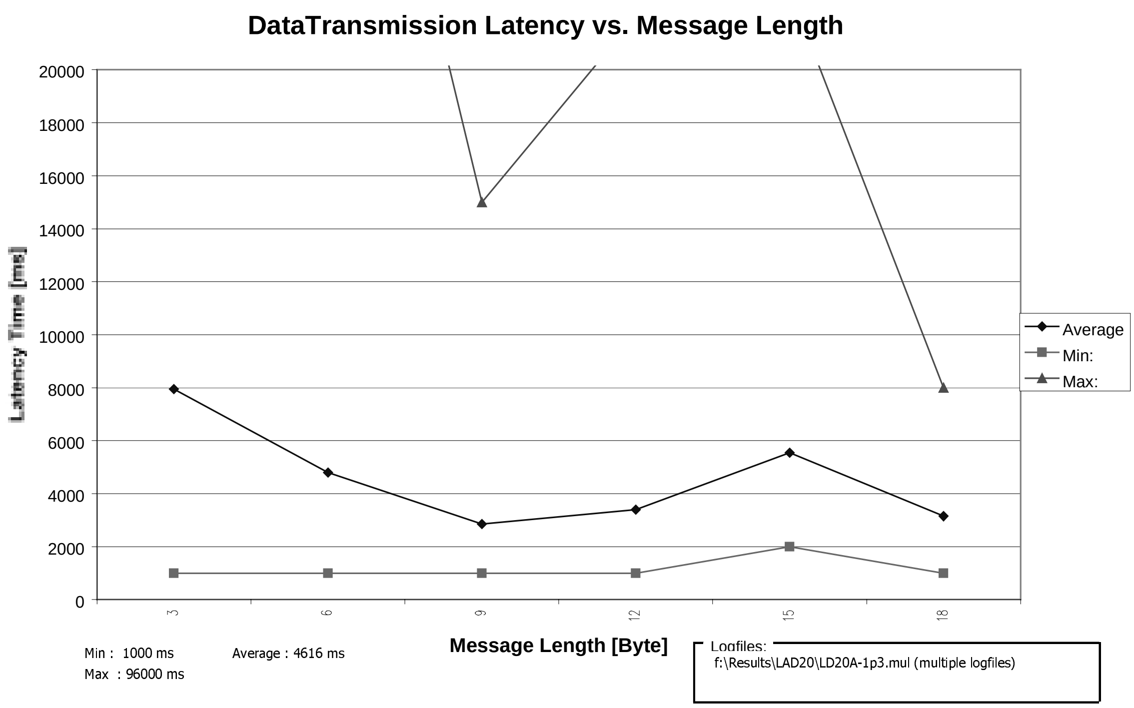

Figure 40: CPDLC Data Transmission Latency Time as a Function of the Message Length (AMSS downlink)

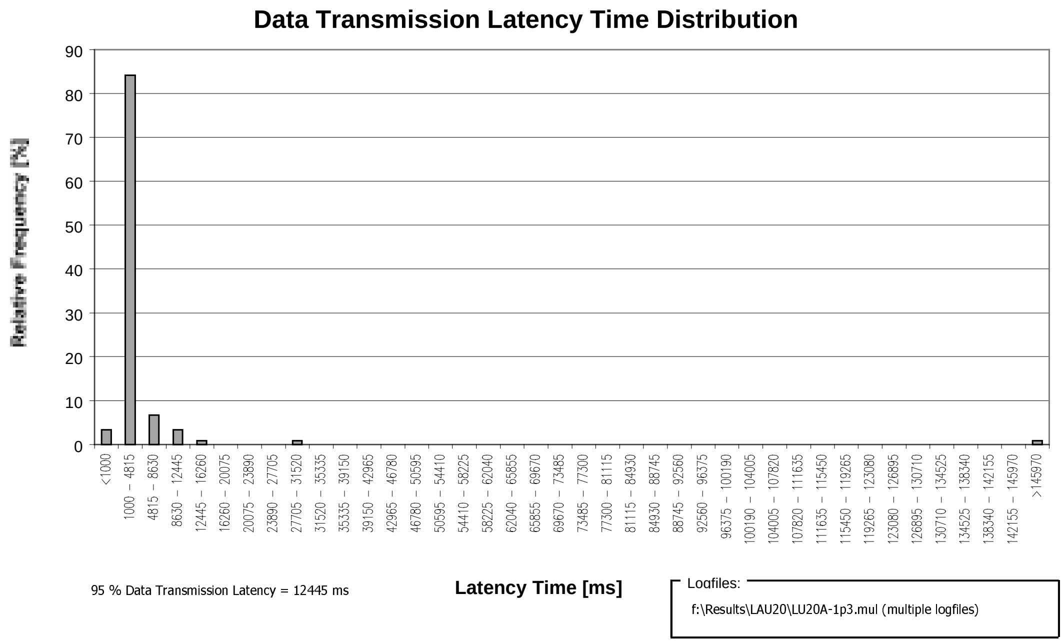

Figure 41: CPDLC Data Transmission Latency Time Distribution (AMSS uplink)

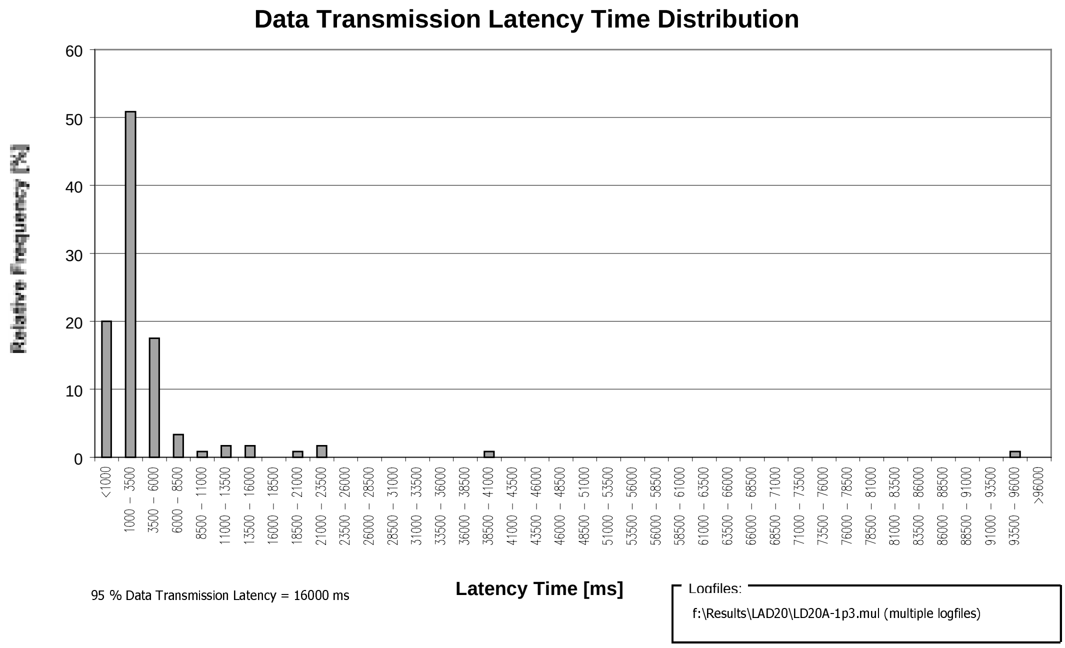

Figure 42: CPDLC Data Transmission Latency Time Distribution (AMSS downlink)

Observations	data link: AMSS		
direction: uplink downlink	experiment ID: LAU20 LAD20	figures: Figure 40 - Figure 42	objectives: CPDLC Data Transmission Latency

1	Significant fluctuations of the Data Transmission Latency can be observed as manifested by the large difference between min and max values. The reason for this observation has already been explained in Table 6 (see observation 1.)
2	No deterministic dependency on the packet length can be observed. The minimum times are almost the same for all packets.
3	In both cases (up- and downlink) the majority of measured delays (more than 60 %) is in the range of 0,8 seconds to 2,8 seconds. This measurement result is consistent with the distribution of the one-way transmission delay in the case of Dialogue Release (see Figure 38). However, the large number of extreme deviations (10 seconds and more), which have a share of about 6 % in the uplink and about 7 % in the downlink is worrying.

Parameter		**Results**	
		uplink	**downlink**
Data Transmission Latency (all message lengths)	min	1 000 ms	1 000 ms
	average	4 100 ms	4 616 ms
	95%	12 445 ms	16 000 ms
	max	96 000 ms	146 000 ms
Average Data Transmission latency boundaries	min	1900 ms (6 Byte)	2200 ms (9 Byte)
	max	18300 ms (18 Byte)	12100 ms (3 Byte)
Test Conditions			
Data 3		1	1
Data 2		133	88

Table 8: CPDLC Data Transmission Latency (AMSS)

6.2.1.3 CPDLC over Mode S

6.2.1.3.1 CPDLC Dialogue Establishment and Release Latencies via Mode S

The test results shown in this section address the CPDLC Application Layer Dialogue Establishment and Release Latencies when using the Mode S subnetwork for transport.

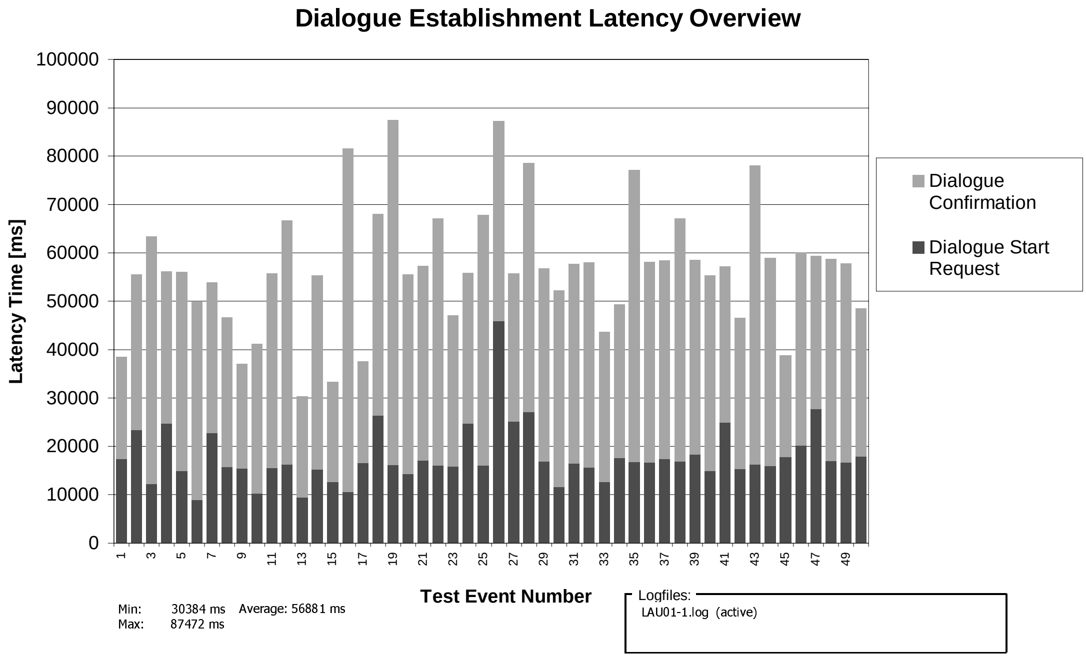

Figure 43: Measured Latency in CPDLC Dialogue Establishment (Mode S ground-initiated dialogue)

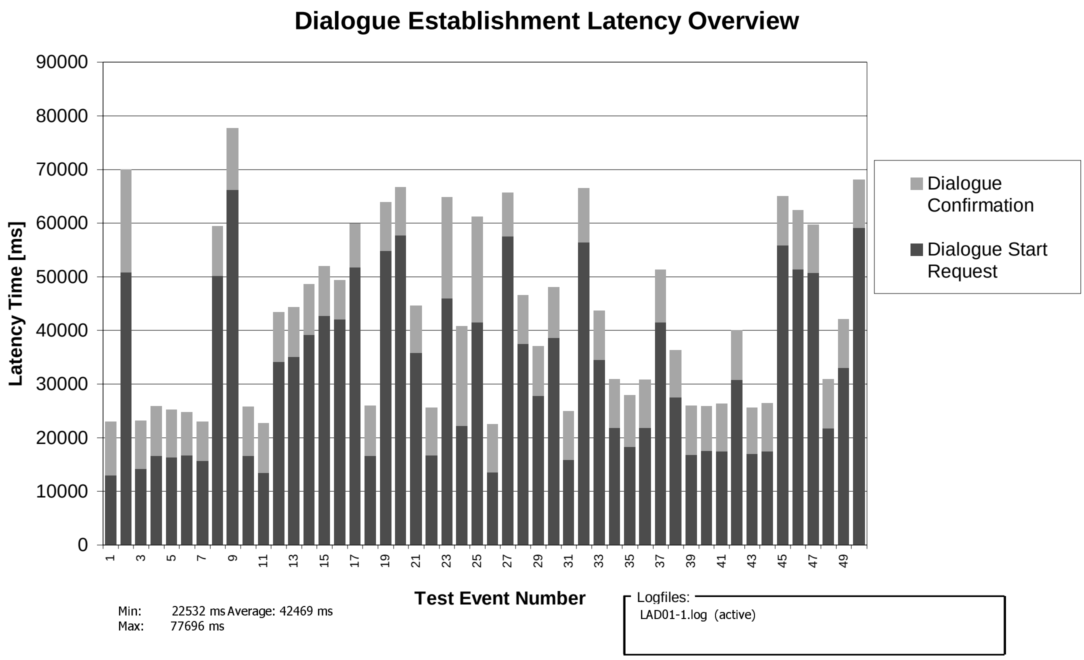

Figure 44: Measured Latency in CPDLC Dialogue Establishment (Mode S air-initiated dialogue)

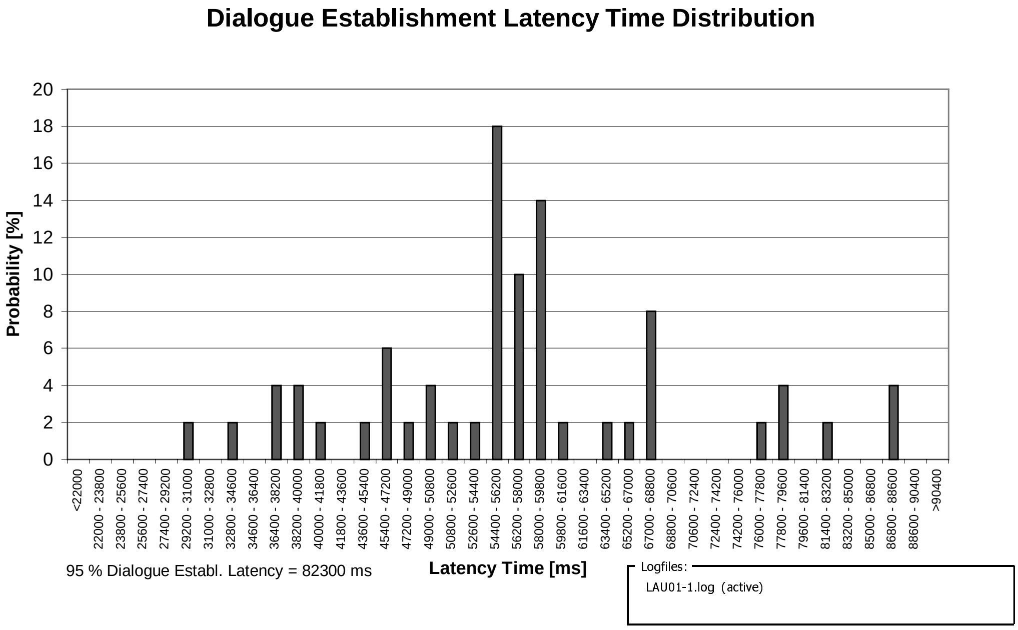

Figure 45: CPDLC Dialogue Establishment Latency Distribution (Mode S ground-initiated dialogue)

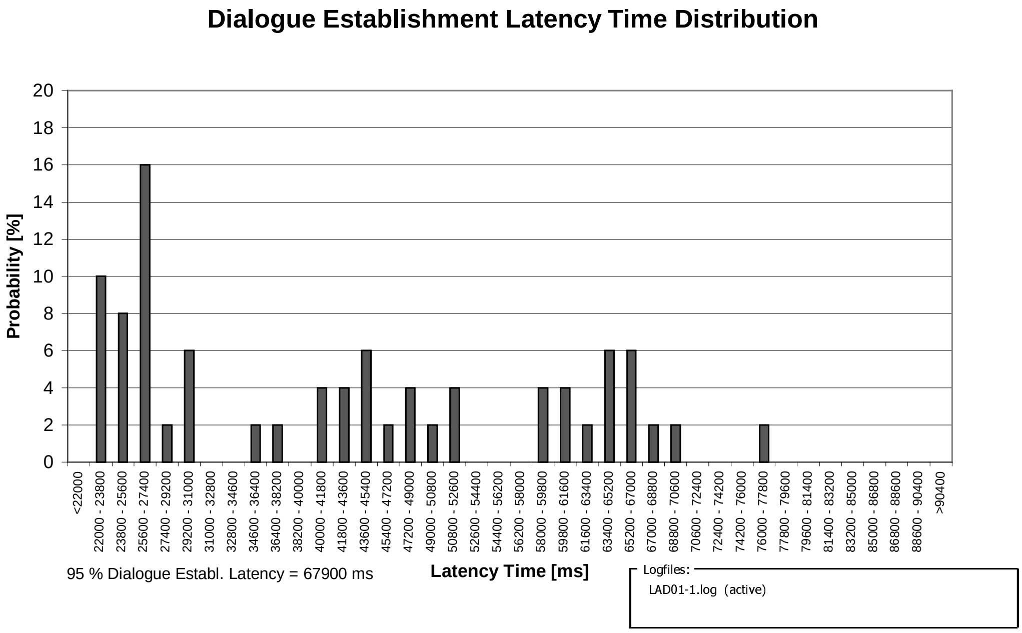

Figure 46: CPDLC Dialogue Establishment Latency Distribution (Mode S air-initiated dialogue)

Observations	data link: Mode S		
direction: ground-initiated air-initiated	experiment ID: LAU01 LAD01	figures: Figure 43 - Figure 46	objectives: CPDLC Dialogue Establishment Latencies

1	Significant fluctuations of the Dialogue Establishment Latency can be observed for both cases, ground-initiated dialogue establishment and air-initiated dialogue establishment. The minimum times are below two antenna revolutions (10 seconds), which suggests that the Dialogue Establishment can be accomplished within two antenna sweeps under normal (timing) conditions. In a few cases however the time is higher than on average. In these cases the Dialogue Establishment Request could not be transferred at the first beam dwell but one or more beam-dwells later. This suggests that the ground air communication was not stable enough so that several antenna rotations were required to deliver the Dialogue establishment Request. The smaller fluctuations in the latency times are caused by the asynchrony of Request times with the antenna rotation so that more or less time is added until the antenna points to the target transponder.
2	On the ground-initiated Dialogue Establishment trials the Dialogue acceptance message returned from air to ground requires much more time than the Dialogue establishment Request itself. On the air- initiated Dialogue Establishment trials the Dialogue Request takes a longer time while the corresponding Dialogue Acceptance message is much quicker. The diagrams in Figure 43 and Figure 44 illustrate that the Mode S uplink has in the used ATN test bed configuration an average transmission delay of about 19 seconds. This average is quite stable for most test cases. With one exception, deviations from this average value are quite modest (in the order of 50% in each direction). In contrast, the downlink exhibits a much larger transmission delay average of about 40 seconds with large deviations. There are only very few test events which are very close to the average value but the measured transmission times vary strongly in a range from 12 seconds up to 75 seconds. It is assumed that this is not caused by different processing delays but possibly due to problems in the RF link. The downlink times would at first be expected to be one antenna revolution longer than the uplink times since each downlink message first has to be announced to the radar before it is transmitted to the ground. However the times are in some cases three times as long. The extra delay may possibly be attributed to weak and distorted transmissions of the transponder, so that the radar only saw the transponder reply after several retries which consequently requires several antenna revolutions rather than only one extra antenna revolution. A Transponder antenna cable problem was detected later. A repetition of the test couldn't be performed due to missing maintenance support.
3	In both cases (i.e. ground-initiated and air-initiated dialogue establishment) the shape of the measurement curve of the Total Dialogue Establishment Time is quite similar and mainly influenced by the large variations in the downlink. However, dialogue establishment requires about 10 seconds less, if the dialogue is air-initiated as compared to ground-initiated. This behaviour is in conflict with the theory, since gound initiated transactions need one transaction cycle less than air

Observations	data link: Mode S		
direction: ground-initiated air-initiated	experiment ID: LAU01 LAD01	figures: Figure 43 - Figure 46	objectives: CPDLC Dialogue Establishment Latencies

initiated communication. In addition the distribution (Figure 45) for uplink CPDLC Dialogue Establishment Latency point to anomalous system behaviour which is confirmed by the calculated average values of the overall dialogue establishment time (42,4 seconds vs 56,8 seconds) and is therefore obviously dependent on the antenna rotation period (10 seconds) and the data processing implementation.

Parameter		Results	
		Ground-initiated	**Air-initiated**
Total Dialogue establishment latency	min	30 384 ms	22 532 ms
	average	56 881 ms	42 469 ms
	95%	82 300 ms	67 900 ms
	max	87 472 ms	77 696 ms
Test Conditions			
Aircraft in radar coverage		150	150

Table 9: CPDLC Dialogue Establishment Latencies (Mode S)

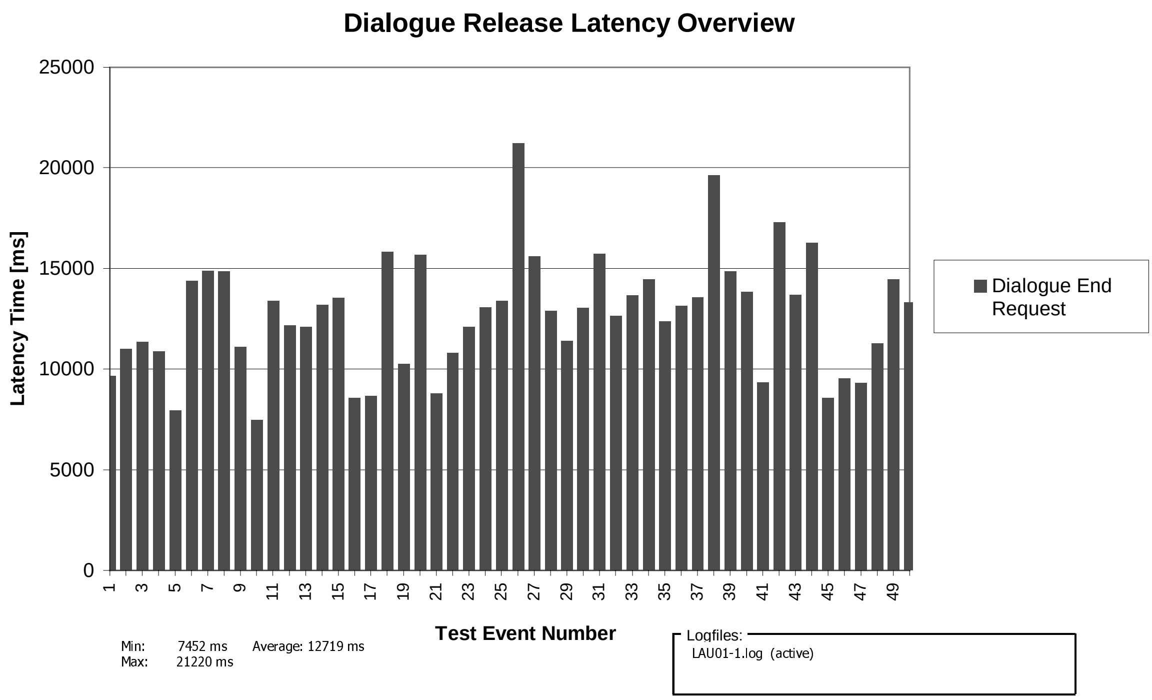

Figure 47: Measured Latency in CPDLC Dialogue Release (Mode S ground-initiated dialogue release)

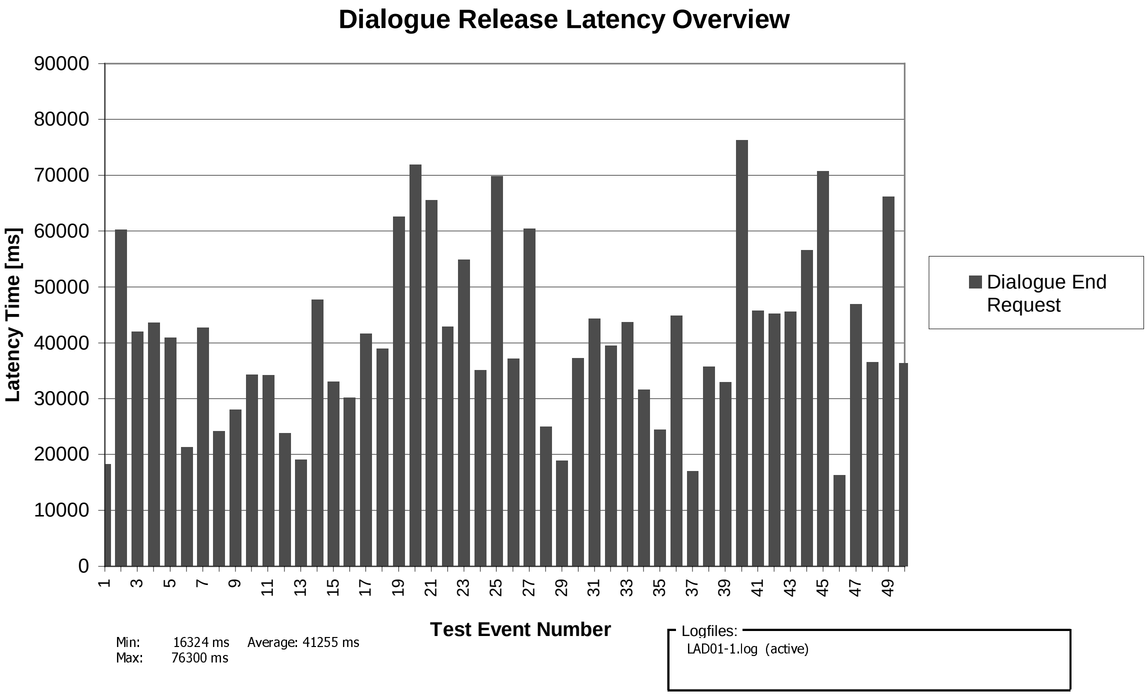

Figure 48: Measured Latency in CPDLC Dialogue Release (Mode S ground-initiated dialogue release after an air-initiated dialogue)

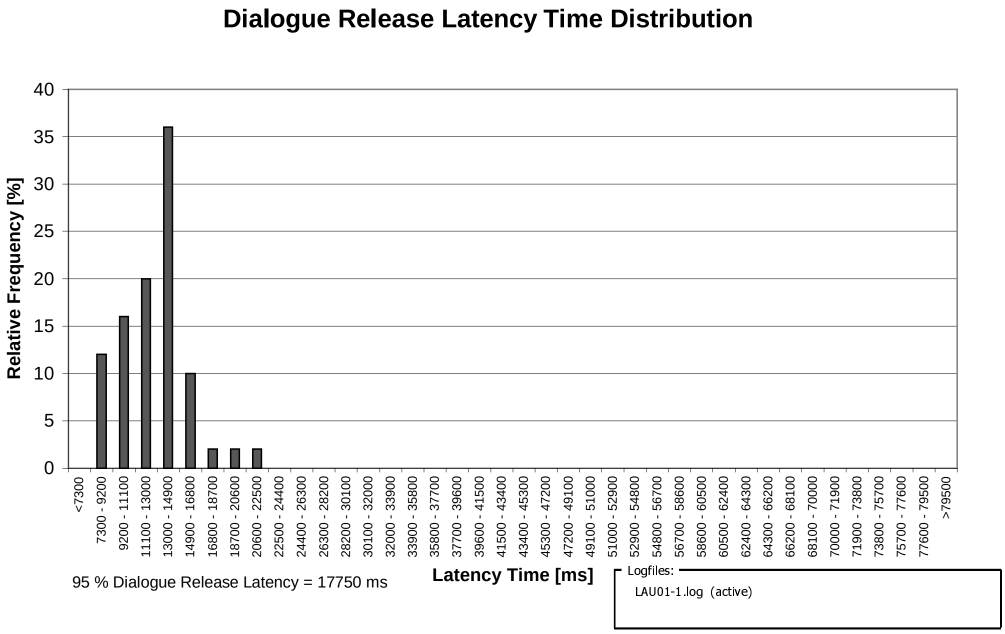

Figure 49: CPDLC Dialogue Release Latency Time Distribution (Mode S ground-initiated dialogue release after a ground-initiated dialogue)

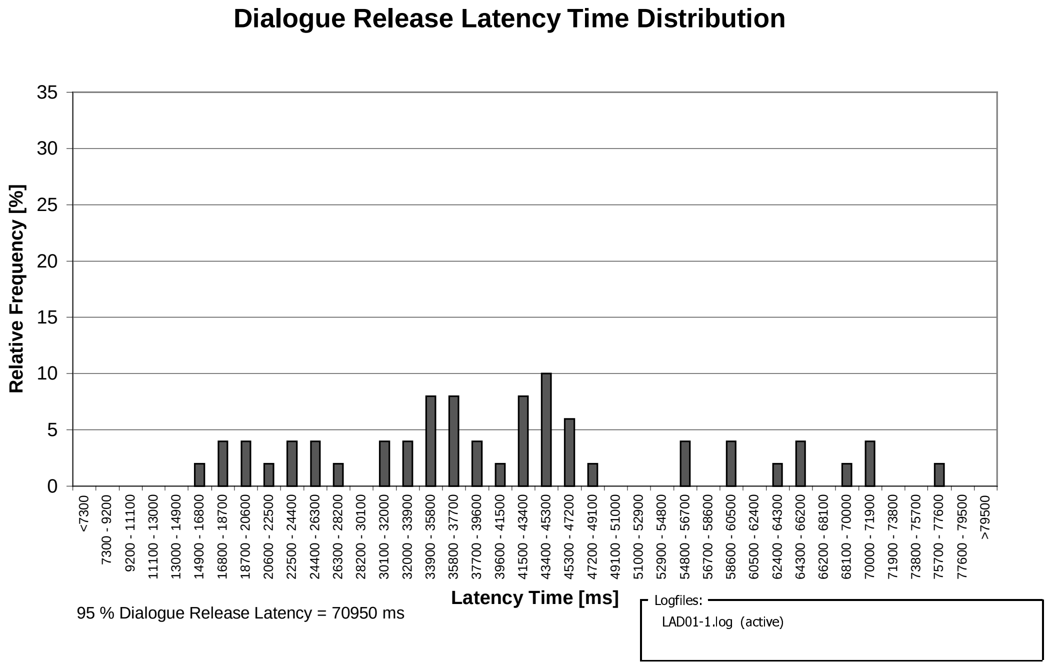

Figure 50: CPDLC Dialogue Release Latency Time Distribution (Mode S air-initiated dialogue release)

Observations	Data link: Mode S		
direction: ground-initiated air-initiated	Experiment ID: LAU01 LAD01	figures: Figure 47 - Figure 48	objectives: CPDLC Dialogue Release Latency

1	Significant fluctuations of the Dialogue Release Latency can be observed during the progress of a test-run. The smaller fluctuations in the latency times are caused by the asynchrony of Request times with the antenna rotation so that more or less time is added until the antenna points to the target transponder.
2	The average Dialogue Release Latency is much higher in the case of an air-initiated dialogue than in the ground-initiated case. The reason for this difference is attributed to the fact that the delivery of a downlink message requires one extra antenna revolution more than on the uplink. Extra time was required due to weak and distorted transponder signal at the interrogator, thus causing retries.
3	

Parameter		**Results**	
		Ground-initiated	**Air-initiated**
Dialogue Release Latency	min	7 452 ms	16 324 ms
	average	12 719 ms	41 255 ms
	95%	17 750 ms	70 950 ms
	max	21 220 ms	76 300 ms
Test Conditions			
Aircraft in radar coverage		150	150

Table 10: CPDLC Dialogue Release Latency (Mode S)

6.2.1.3.2 CPDLC Data Transmission Latencies via Mode S

The test results shown in this section address the CPDLC Application Layer Data Transmission Latencies when using the Mode S sub-network for transport.

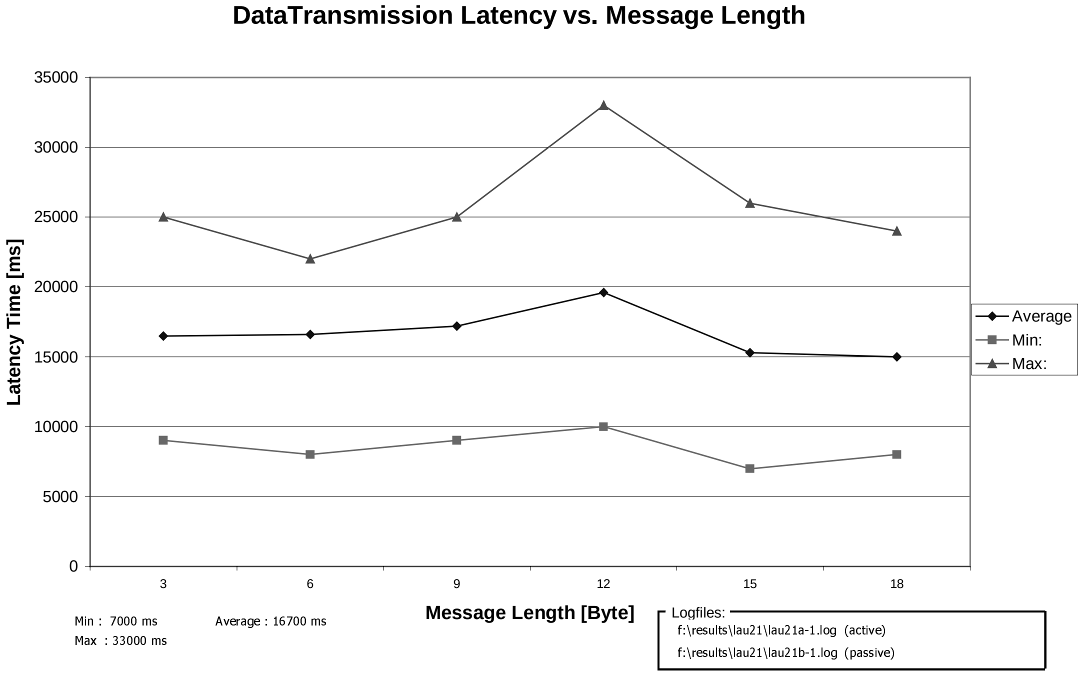

Figure 51: CPDLC Data Transmission Latency as a Function of the Message Length (Mode S uplink)

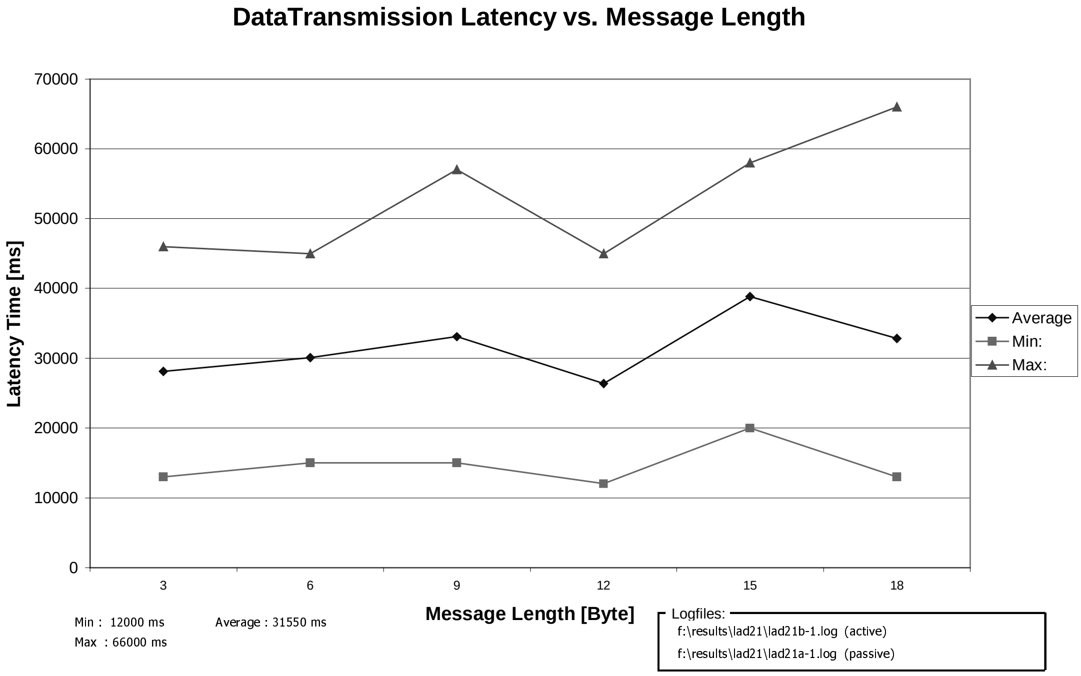

Figure 52: CPDLC Data Transmission Latency as a Function of the Message Length (Mode S downlink)

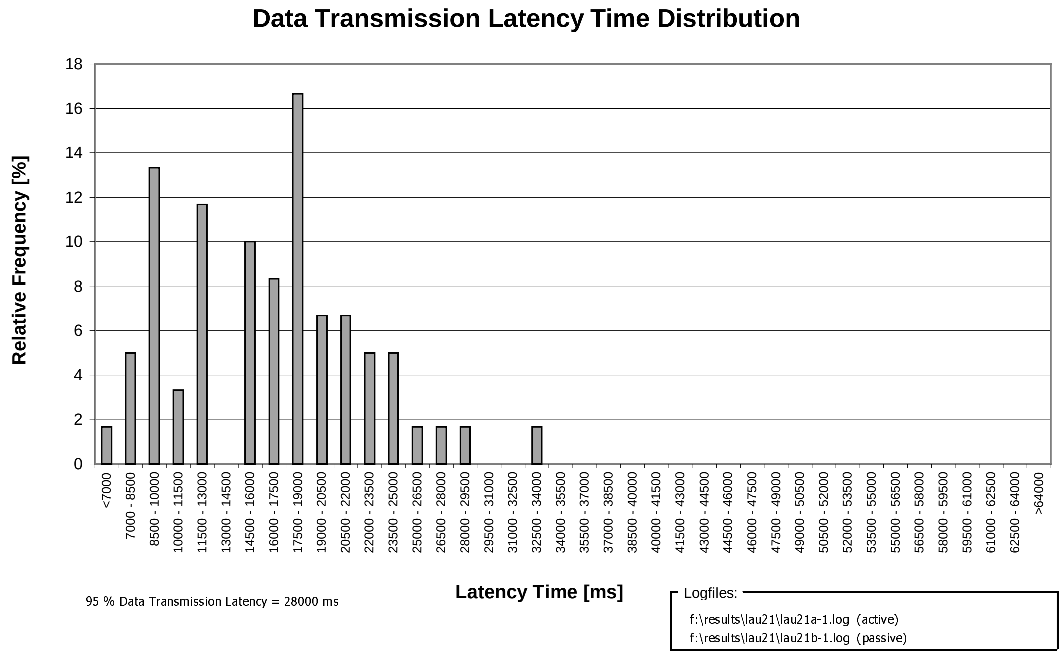

Figure 53: CPDLC Data Transmission Latency Time Distribution (Mode S uplink)

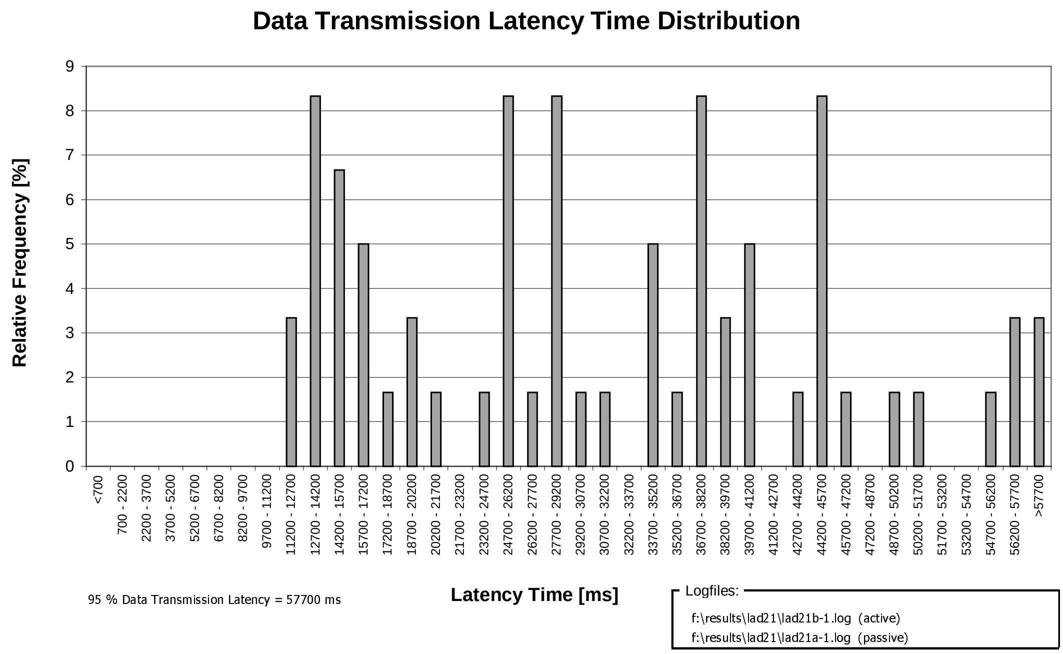

Figure 54: CPDLC Data Transmission Latency Time Distribution (Mode S downlink)

Observations	data link: Mode S		
direction: uplink downlink	Experiment ID: LAU21 LAD21	figures: Figure 51 - Figure 54	objectives: CPDLC Data Transmission Latency

1	The CPDLC Data Transmission Latency is almost independent from the data length which varied between 19 and 29 seconds. The different CPDLC message data is always transferred by the same message formats, so that no difference is observed between short and long messages.
2	The downlink CPDLC Data Transmission Latency is significantly higher than on the uplink. The reason for this difference is attributed to the fact that the delivery of a downlink message requires one extra antenna revolution more than on the uplink. Extra time was required due to week reception of the transponder signal at the interrogator, thus causing retries.
3	In the uplink the minimum, average and maximum transmission delays are quite close to those figures measured during the Dialogue Establishment and Dialogue Release trials. This confirms the „stability“ of the Mode S uplink channel (see above). On the downlink however, the minimum, average and maximum transmission delays are better than for the Dialogue Establishment and Dialogue Release trials.
4	Figure 54 clearly displays in the left part of the diagram the delay caused by the announcement of the downlink transmission prior to the actual transmission of the message. The gap in the most left part of the histogram corresponds to one antenna revolution time which was 10 seconds.

Parameter		**Results**	
		uplink	**downlink**
Data Transmission Latency (all message lengths)	min	7 000 ms	12 000 ms
	average	17 000 ms	32 000 ms
	95%	28 000 ms	58 000 ms
	max	33 000 ms	66 000 ms
Average Data Transmission latency boundaries	min	15 000 ms (18 Byte)	26 400 ms (12 Byte)
	max	19 600 ms (12 Byte)	38 800 ms (15 Byte)
Test Conditions			
Aircraft in radar coverage		170	170

Table 11: CPDLC Data Transmission Latency (Mode S)

6.2.2 Data Link Layer Trials

6.2.2.1 Objectives

Two separate sets of investigations were undertaken in the course of the Project: The results described in chapter 6.2.1 Application Layer Trials are based on investigations that made use of experimental data link systems and experimental data link applications.

These application layer investigations provided in the fist instance capability characteristics of the overall environment which consists of different data link systems, end systems and data link applications. A focus on the different data links and their properties was not possible with the application layer trials (chapter 6.2.1).

An analysis of the different data links was then conducted under a more technical point of view. For this purpose, only those characteristics and interfaces were investigated which allow further theoretical analysis based on future user requirements.

The data link layer of the OSI 7 layer model provided a suitable interface to achieve these results and was consequently used.

6.2.2.2 NEAN

6.2.2.2.1 General

For the NEAN data link it was intended to determine

1. The available Transfer rate and packet rate per user,
2. The Data Transmission Latency and Data Integrity

Call Setup and Call Clearing tests could not be performed with the NEAN data link since it is not connection oriented.

Initial data transmission tests showed that the NEAN data link was very sensible to the packet rate supplied. Therefore an additional test objective was added to determine the packet rate limits.

The NEAN Data link supports message lengths of up to 52 NEAN characters per packet. 6 bits encode each NEAN character. To make the messages as long as in the case of byte oriented data links a conversion was implemented which grouped any 3 characters of the test message to 4 NEAN characters so that the same message length as for the byte oriented data links was created.

To accommodate messages between 3 bytes and 1020 bytes as foreseen by the tests the NEAN interface in the DLTE had implemented a simple "More-Character" mechanism to allow the split and recombination of the longer test-messages. The relatively high loss rate observed in the NEAN data link resulted in a large number of lost NEAN packets so that the recombined More-Character messages were to a great extent corrupted and did not allow a proper evaluation. It was therefore decided to only use test messages, which contained between 3 and 39 Bytes, which resulted in NEAN message lengths between 4 and 52 NEAN (6-bit) characters.

Under the assumption that a more robust split and recombination mechanism would allow transferring longer messages as well, the resulting theoretical transmission latencies were derived from the obtained results for the shorter messages.

6.2.2.2.2 NEAN User Data rate and Packet rate

The available NEAN user data- and packet rate was measured with a sending packet interval of 333 ms so that the NEAN data link was operated at its limits and thus limited the data throughput (see chapter 6.1.2). The following figures show the resulting receive data rates and packet rates measured at the receiving end of the data link.

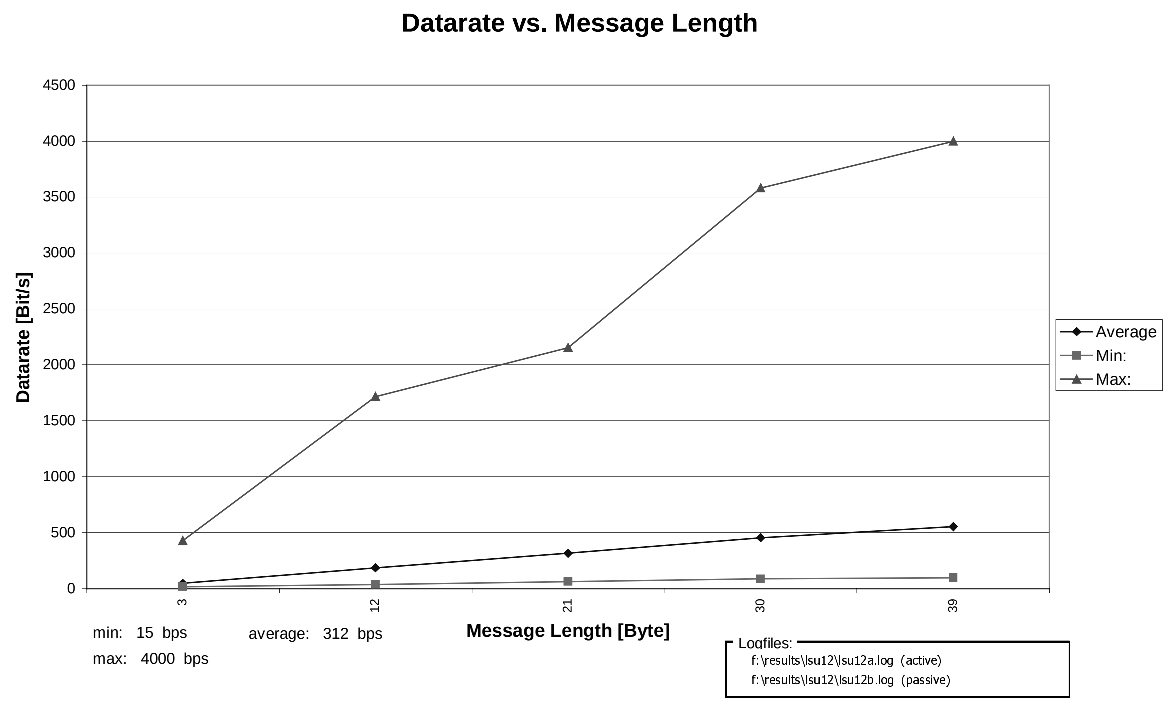

Figure 55: NEAN Uplink Data rate vs. Message Length

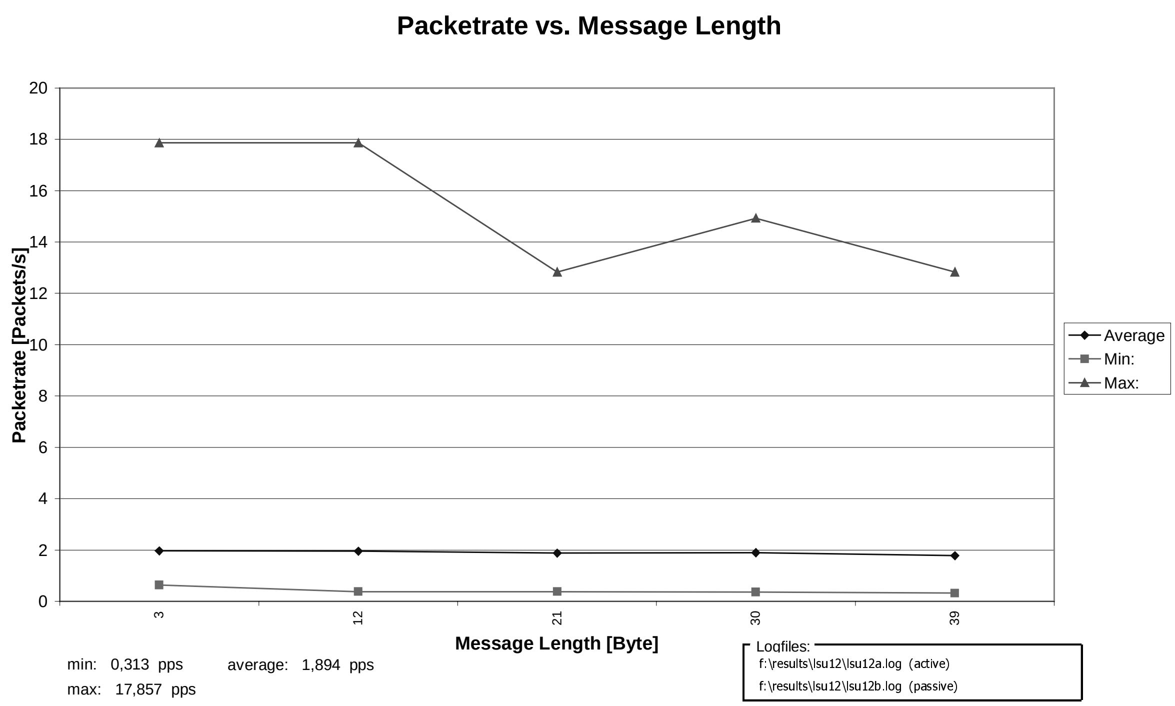

Figure 56: NEAN Uplink Packet rate

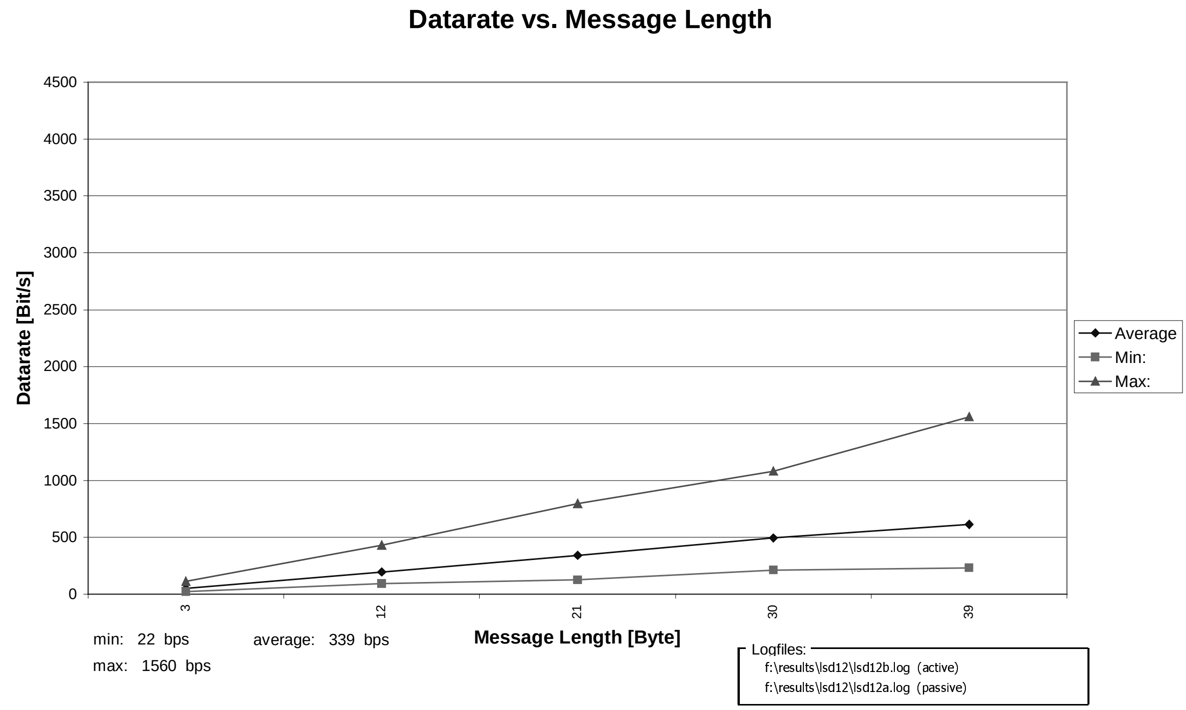

Figure 57: NEAN Downlink Data rate vs. Message Length

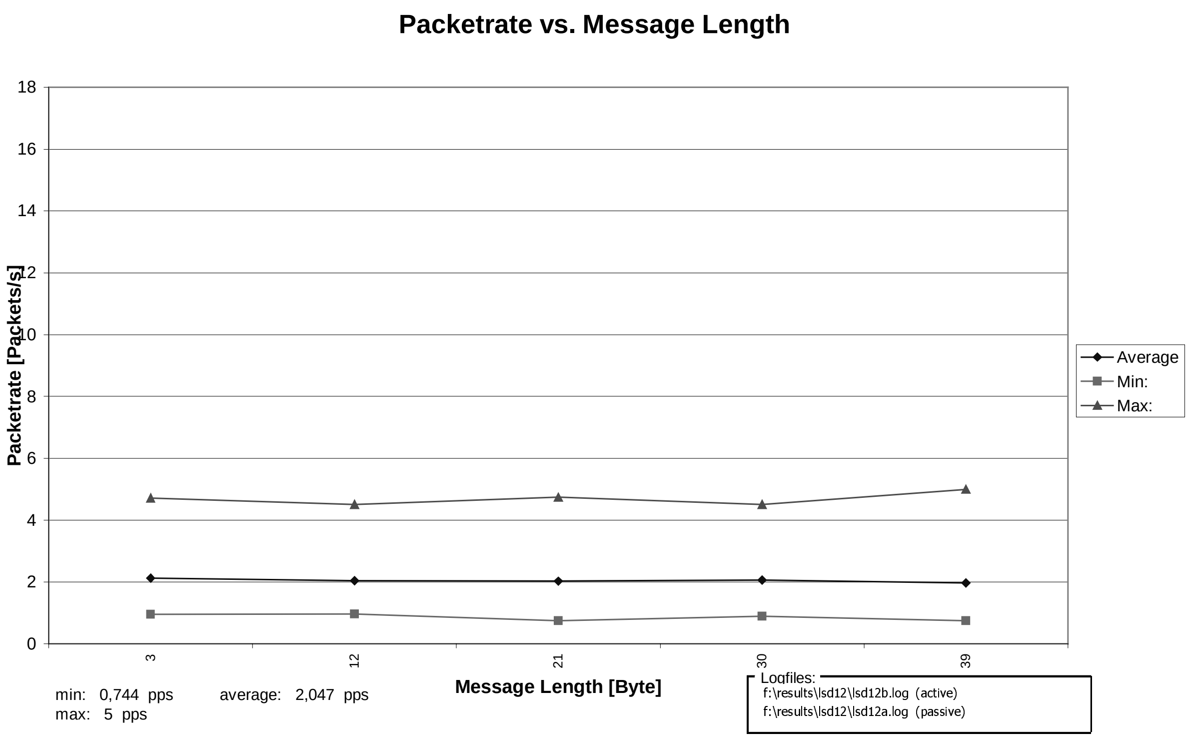

Figure 58: NEAN Downlink Packet rate vs. Message Length

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU12 LSD12	figures: Figure 55 - Figure 58	objectives: User Data Rate

1	The average transfer rate increases almost linear with the packet length while the resulting packet rate is almost constant The limitation of the NEAN data rate is primarily caused by a limitation of the packet rate. As the NEAN data link is limited by the maximum packet rate (i.e. 3 packets per second) and not limited by its data rate, the overall transfer rates increases with the number of bits contained per packet.
2	The NEAN uplink and downlink exhibit more or less the same transmission characteristics with respect to the measured data rate and packet rate respectively. This is due to the fact that the same channel structure and access protocol is used in both directions.
3	The limitation of the transfer rate was simply caused by loosing data packets as determined by comparing the send and received data. No flow control mechanism is foreseen which throttles down the data source.
4	The maximum transfer rates are much higher than the average transfer rates. On the uplink this increase is more significant than on the downlink. The maximum rates apply to single events. In those cases two successive packets were delivered to the DLTEs very shortly after each other, so that the momentary bit rate and packet rate were significantly increased. On the airborne installation (downlink) the DLTE is directly coupled to the NEAN transponder so that the transport of two successive packets at a short interval is fully visible by the airborne DLTE. On the ground installation (uplink) the data packets are first routed through the Local Server in Frankfurt, the PSN and the Local Server in Langen, which obviously rough the packet rate delivered by the transponder so that events when a high packet rate occurs are more frequent. The average value describes the available transfer rate more realistically than the maximum values.

Parameter		**Results**	
		uplink	**Downlink**
Transfer-Rate	min	15 bit / s	22 bit/ s
	average	312 bit/s	339 bit/s
	max	4.000 bit/s	1.560 bit/s
Packet-Rate	min	0,313 pps	0,744 pps
	average	1,894 pps	2,047 pps
	max	17,857 pps	5 pps
Test Conditions			
Number of Users		2-3	2-3

Table 12: User Data Rate (NEAN)

6.2.2.2.3 Data Transmission Latency and Data Integrity

After the observation that the NEAN data link is highly sensible to changes in the packet rate, seven different sending packet intervals between 440 ms and 1000 ms were used to investigate the dependency on the packet interval. The results are presented in Figure 59 and the following figures.

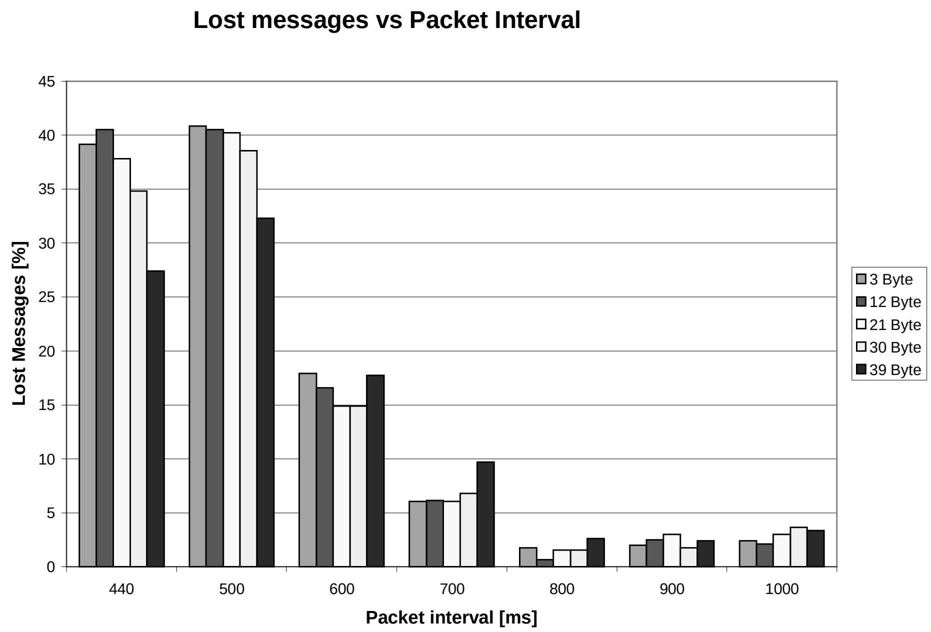

Figure 59: Dependency of Lost Messages on the Packet Interval (NEAN Uplink)

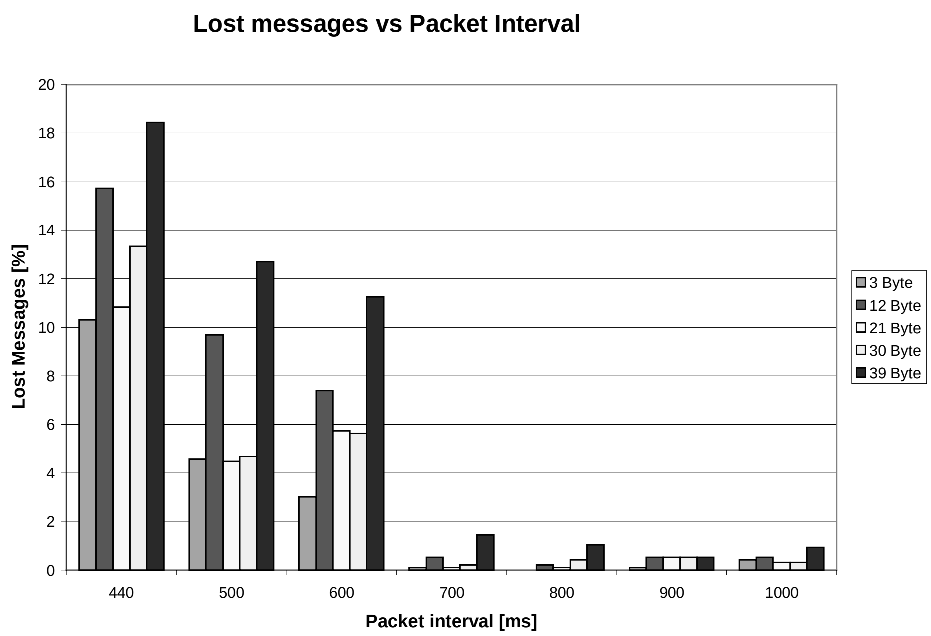

Figure 60: Dependency of Lost Messages on the Packet Interval (NEAN Downlink)

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 59 & Figure 60	objectives: number of lost packets vs. sending packet interval

1	The percentage of lost packets decreases from very high levels to moderate levels when the packet interval increases. From a particular packet interval onwards it stays more or less constant. It does not reach 0 % ! A too high packet rate forces the transmission channel into saturation, even in the absence of any interference. Since no flow control exists in the NEAN data link the only way to adjust the throughput to the channel capacity is to throw away packets. An overloading of the data link causes the high loss rate at short packet intervals. The remaining loss rate at high packet intervals probably indicates that even at sufficiently low packet rates some messages are lost due to other problems. There is no end-to-end control mechanism to ensure delivery of packets. The acknowledgement mechanism used on the RF link is not sufficient alone. Other sections of the data link cause lost packets.
2	The loss rate is almost independent from the packet length. All messages of different length are transferred with one single NEAN packet. Therefore no significant difference would be expected in theory.
3	The loss rate on the uplink is significantly higher than on the downlink The precise reason for this observation could not be determined but the following two aspects might have caused this: (i) Due to the fact that the architecture of the NEAN system is symmetric, it was assumed that the increased loss rate on the uplink as compared to the downlink was caused by the different transponders involved in the test. Since the uplink is much weaker than the downlink there is either a lower transmission power of the ground station (or poor antenna matching) or the transponder on the aircraft had a lower sensitivity. As both transponders should in principle have similar capabilities and the RF channel is symmetrical anyway this suggests that the poorer results on the uplink were caused by poor equipment performance only and not by system properties. It can be expected that a properly set up operational system can at least achieve the performance measured on the downlink. (ii) The air DLTE which was directly connected to the air transponder generated a smoother packet rate than was transferred to the ground transponder via the ground networks (Packet intervals could have been changed on the network so that some packets arrived with a too short packet interval) Packets arriving to quickly at the transponder are simply ignored and thereby lost.

Parameter		**Results**	
		uplink	**downlink**
Packet losses	min	~1.5% (800 ms interval)	~0.4% (800 ms interval)
Required minimum packet interval		800 ms	700 ms

Test Conditions

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 59 & Figure 60	objectives: number of lost packets vs. sending packet interval
Number of Users		2-3	2-3

Table 13: Number of lost packets vs. sending packet interval (NEAN)

The optimal packet intervals derived from the overview (Figure 60 and Figure 61) is 800 ms for the uplink and 700 ms for the downlink. These test results related to these sending packet intervals were chosen for the detailed result analysis.

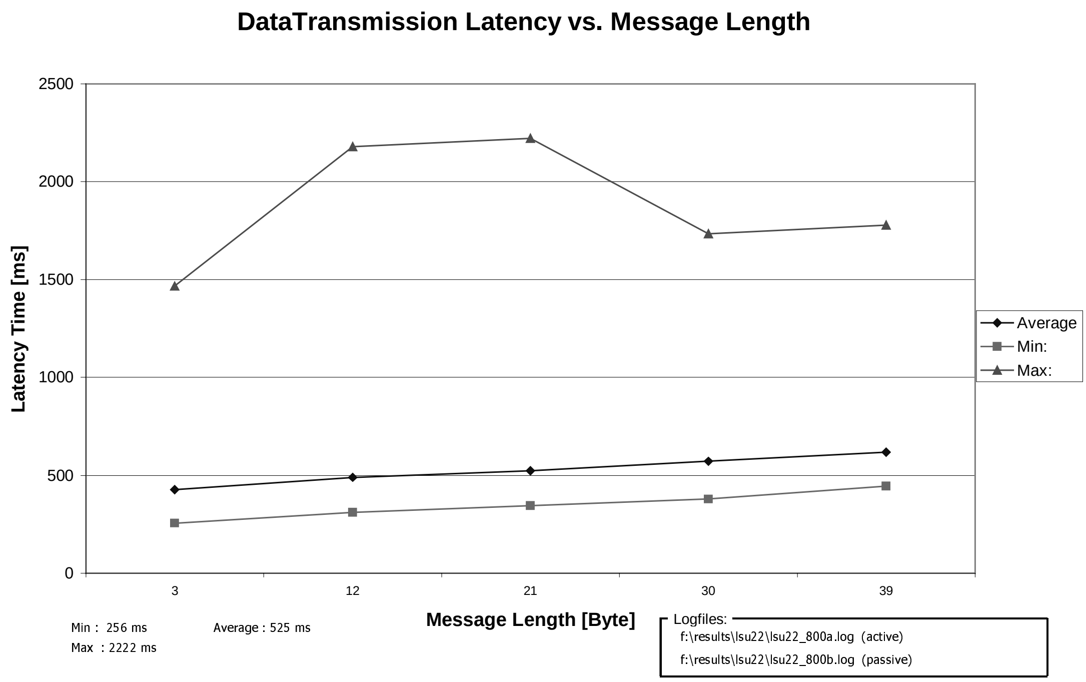

Figure 61: NEAN Data Transmission Latency Uplink

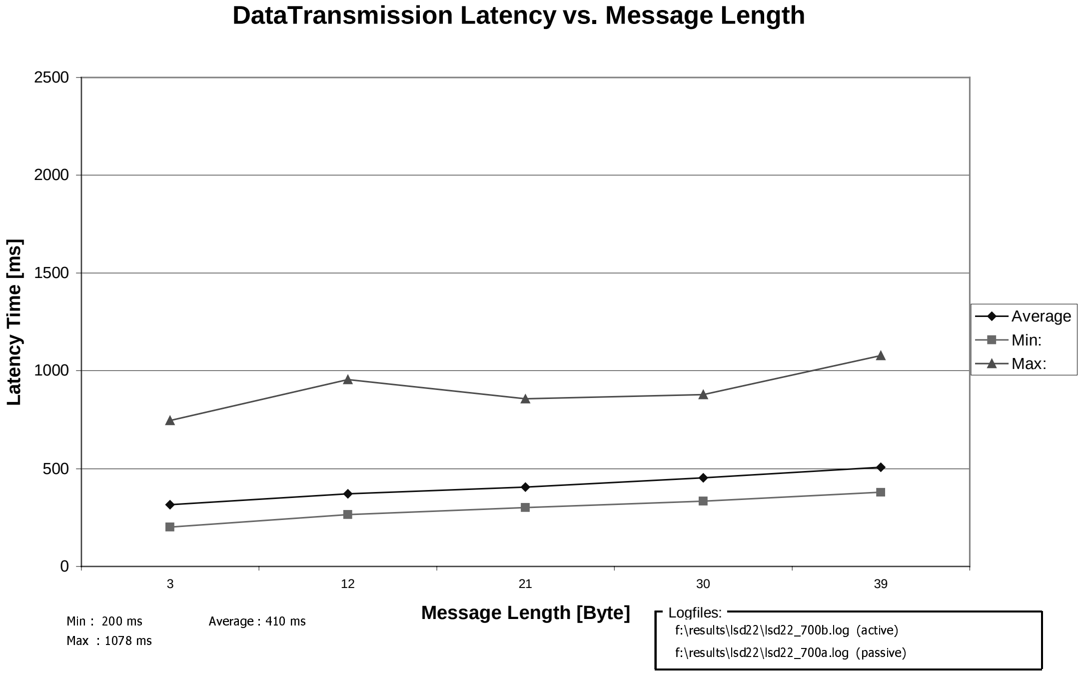

Figure 62: NEAN Data Transmission Latency Downlink

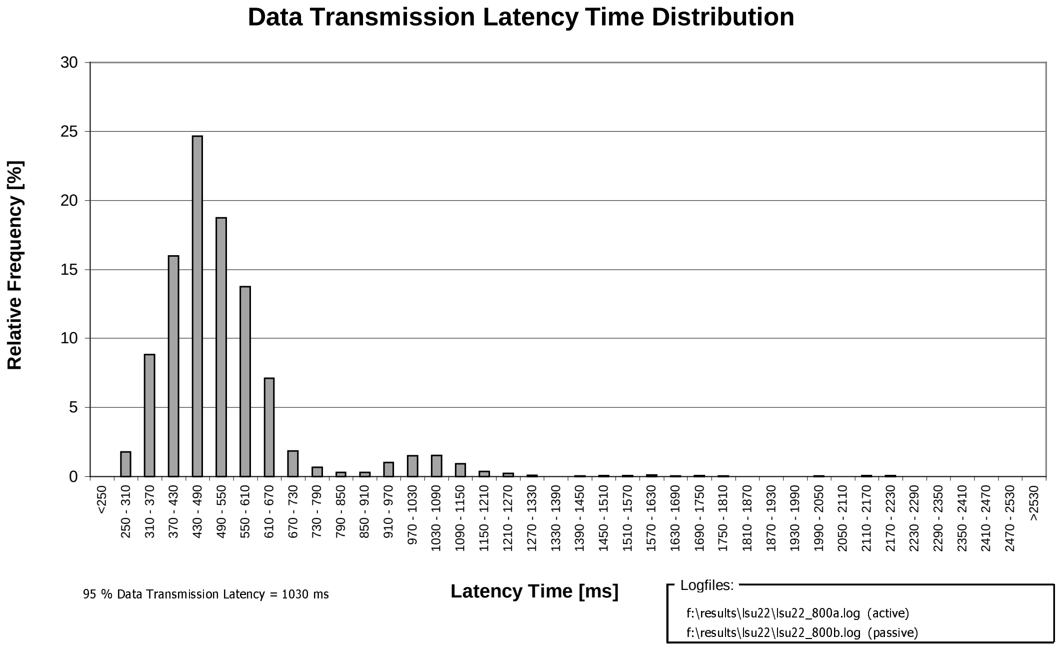

Figure 63: NEAN Data Transmission Latency Distribution Uplink

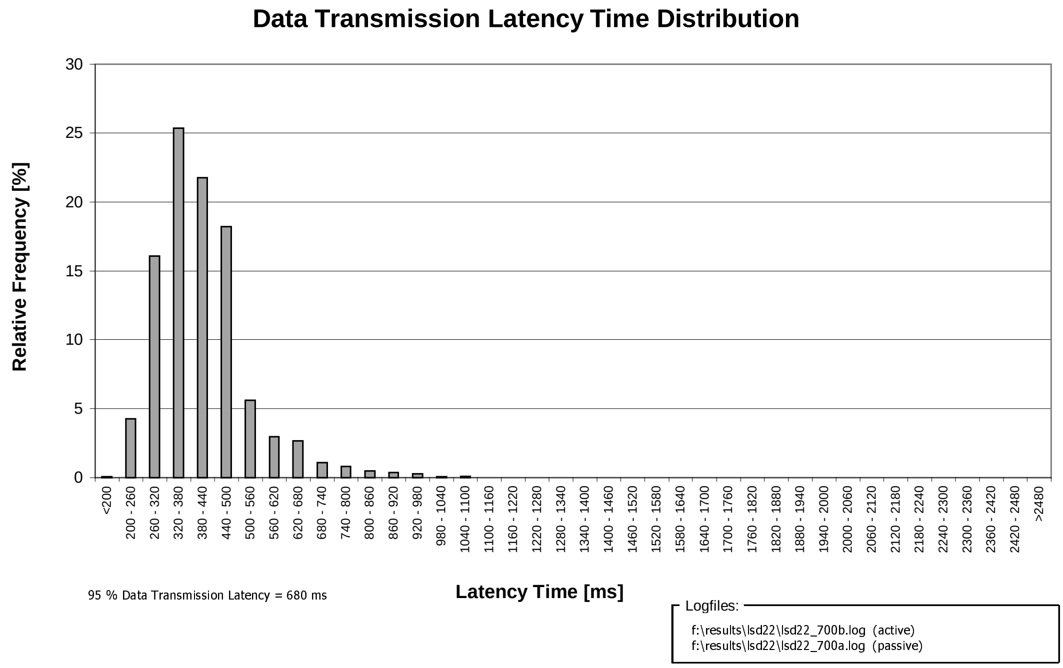

Figure 64: NEAN Data Transmission Latency Distribution Downlink

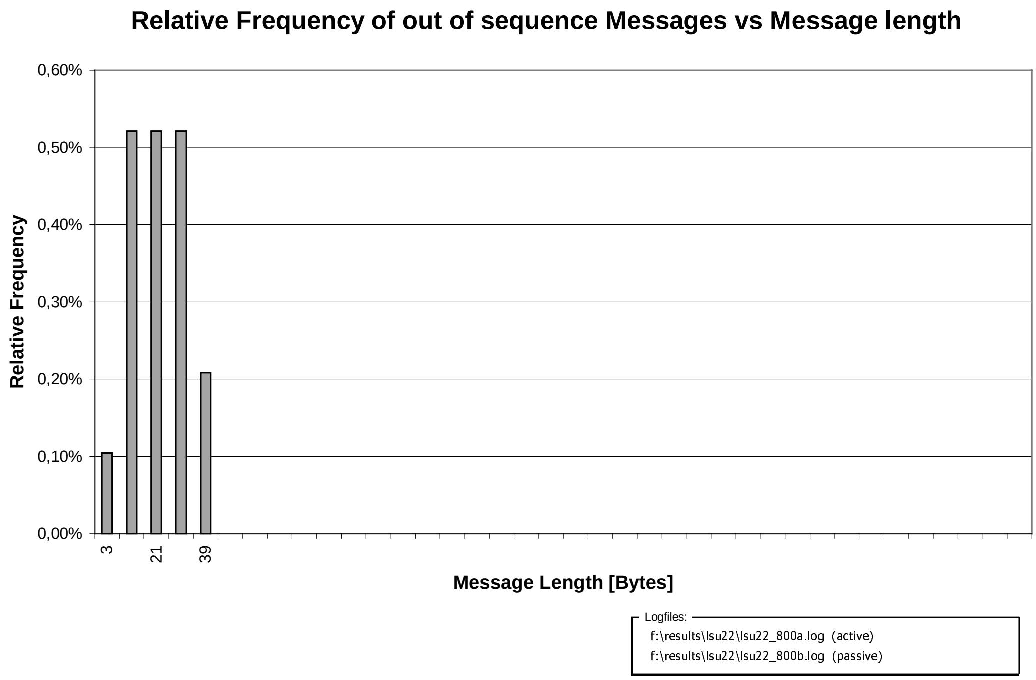

Figure 65: NEAN Out of Sequence Messages Uplink

No out of sequence messages were observed on the downlink.

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 61 - Figure 65	objectives: data transmission latency, out of sequence messages

1	The average Data Transmission Latency slightly increases with the number of Bytes transferred. Figure 61, Figure 62 The slight increase of the data transmission latency can be attributed to the increasing length of the messages, which require more transmission time across the serial interfaces.
2	The maximum values of the data transmission latency are much higher than the average values. Figure 61, Figure 62 This means that in some cases the data is obviously stored in queues in the data link for some time, so that it arrives significantly later than on average. This effect is attributed to retransmissions in case no acknowledgement arrives at the sending transponder. On the downlink up to 4 retries are possible and on the uplink up to 2. The data transmission latency distributions (Figure 63 & Figure 64) show that large transmission delays are nevertheless very rare.
3	On the uplink the transmission latency time distribution shows two maxima (Figure 63). No such effect is observed on the downlink. The NEAN data link performs retries if a message is not acknowledged by the receiving transponder. The second maximum is therefore attributed to those messages, which were only delivered after the second retry. The reason that such effect is not observed on the downlink may be attributed to an asymmetry in the RF channel. The fact that retries are required on the uplink also results in a larger average transmission latency.
4	On the uplink messages were received out of sequence but not on the downlink. It is assumed that out of sequence messages (i.e. messages which arrive after messages which were sent later) occur if a message was not properly received by the destination transponder so that the sending transponder repeats the message a second time. In that case the air transponder did either have a less sensible receiver or the sending transponder has a less powerful transmitter. The actual reason could not be proven.
5	The distribution of the transmission delay in Figure 63 and Figure 64 have an almost gaussian shape with no extreme deviations which indicates that for the test configuration the channel capacity was sufficient and the channel access scheme operated properly.

Parameter		Results	
		uplink	**downlink**
Data Transmission Latency	min	256 ms	200 ms
(all message lengths)	average	525 ms	410 ms
	95 %	1030 ms	680 ms
	max	2222 ms	1078 ms
Average Data Transmission latency boundaries	min	428 ms (3 Byte)	317 (3 Byte)

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 61 - Figure 65	objectives: data transmission latency, out of sequence messages
	max	617 (39 Byte)	508 (39 Byte)
Extra latency in case of a retry		~ 610 ms	no retries observed
Test Conditions			
Number of Users		2-3	2-3

Table 14: Data transmission latency, out of sequence messages (NEAN)

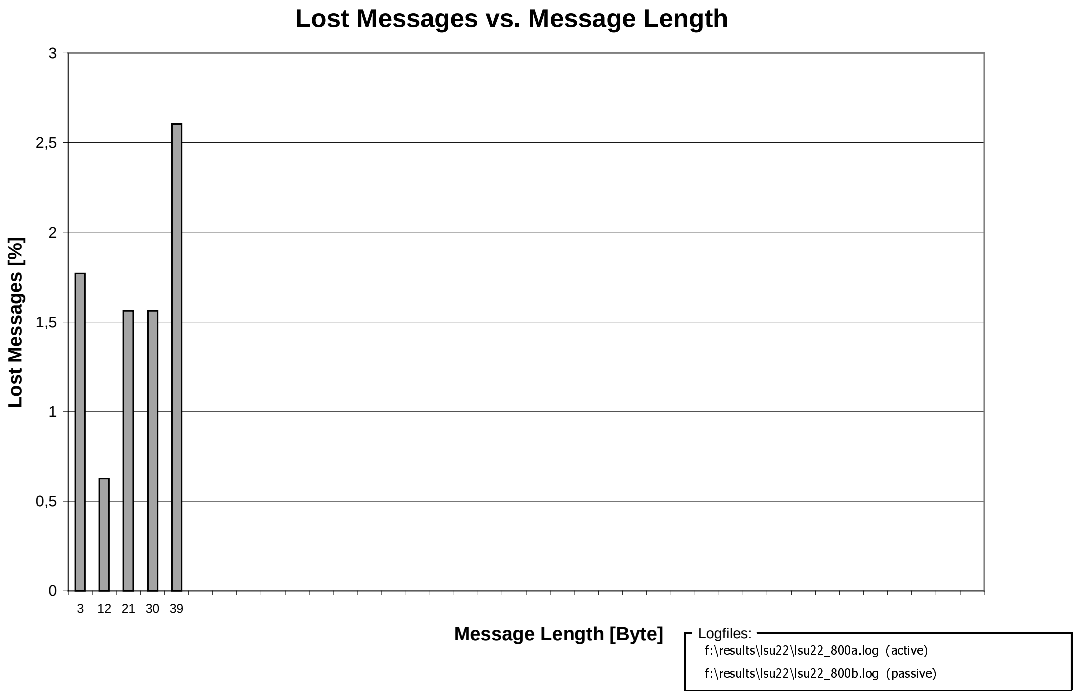

Figure 66: NEAN lost Packets Uplink

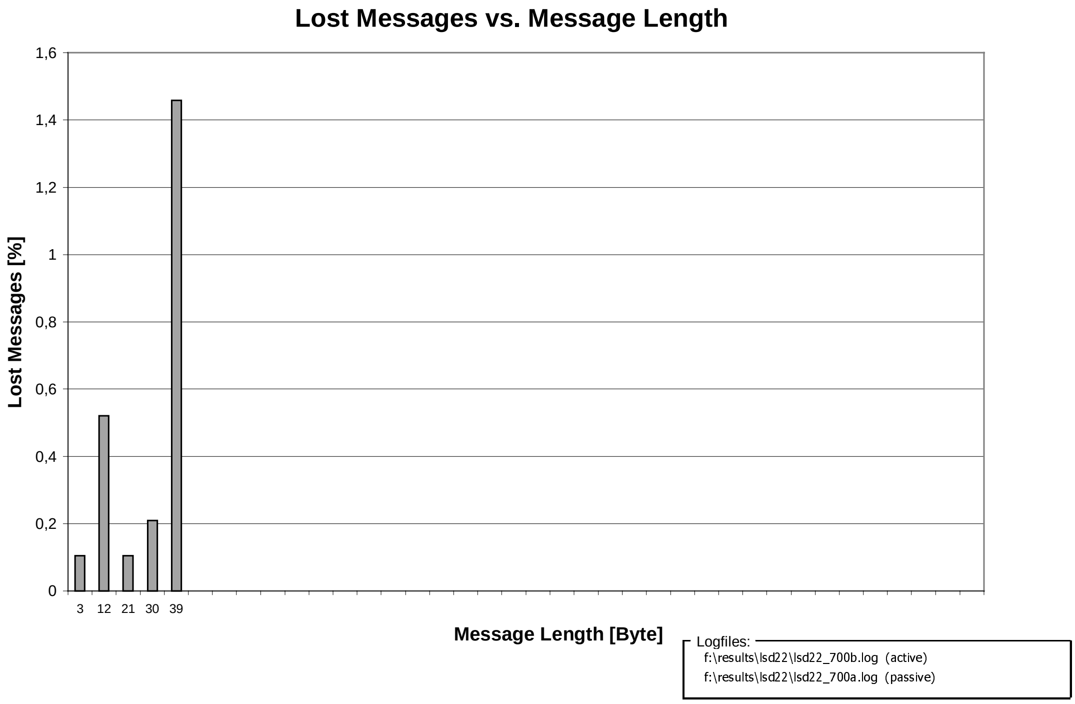

Figure 67: NEAN lost Packets Downlink

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 66 & Figure 67	objectives: lost messages

1	On the uplink and the downlink messages are lost. The loss rates are higher on the uplink than on the downlink. An explanation of this phenomena is given on page 6-80.
2	The loss rates are the highest for the longest messages transferred. The reason for this is certainly that messages are lost somewhere in the channel while no end-to-end acknowledgement detects this.

Parameter		**Results**	
		uplink	**downlink**
Packet Loss Probability	min	0.6 %	0.1 %
	max	2.6 %	1,46%
Test Conditions			
Number of Users		2-3	2-3

Table 15: Lost messages (NEAN)

NEAN could not be tested with long messages (> 39 Bytes) as it was done for the other data links due to the unavailability of a sufficiently robust message split and recombination protocol. Therefore only short messages were used for the NEAN trials.

For comparison reasons the expected transmission latency values were calculated in a spreadsheet based on the transmission latency results of the short messages. The results are shown below.

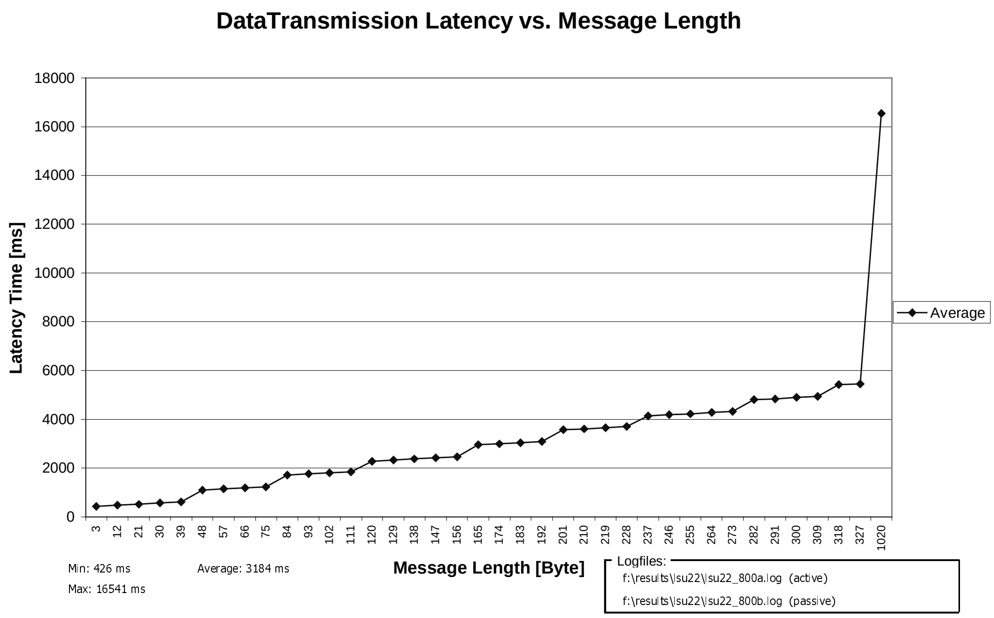

Figure 68: Extrapolated NEAN Message Transfer Latencies (uplink)

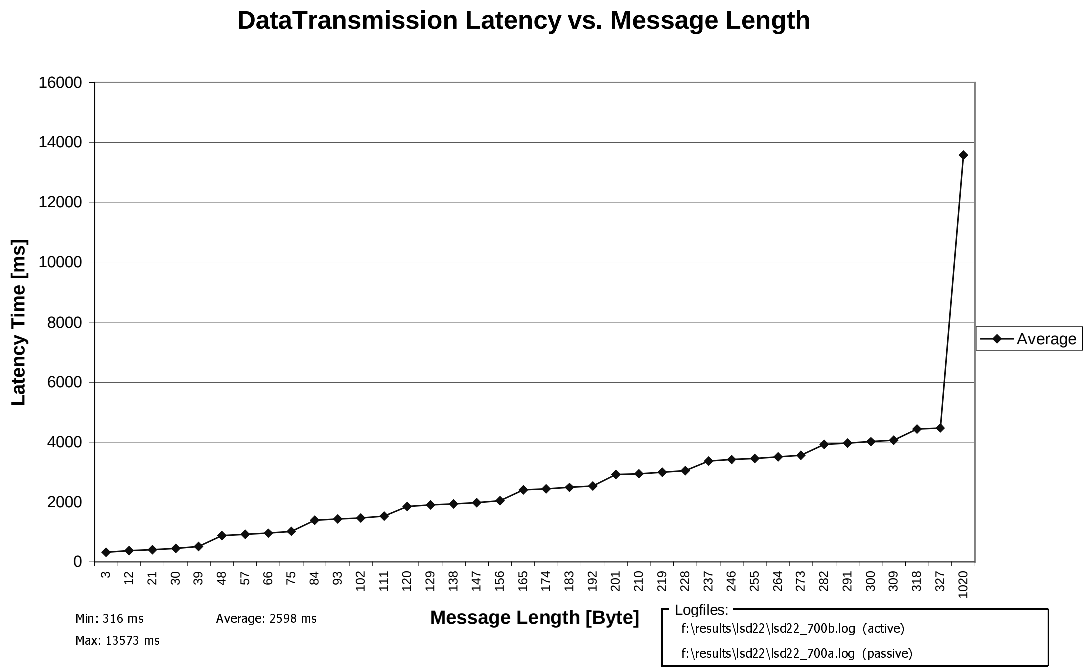

Figure 69: Extrapolated NEAN Message Transfer Latencies (downlink)

Observations	data link: NEAN		
direction: uplink downlink	experiment ID: LSU22 LSD22	figures: Figure 68& Figure 69	objectives: Extrapolated Transmission Latencies for message lengths up to 1020 Byte

1	The extrapolated data transmission latencies increase with the message length The maximum NEAN packet size is 54 character. Because the NEAN system is built up on 6-bit character operation, 3 bytes (1 byte = 8 bit) have to be divided in 4 6-bit character for the transmission. This means that the packet size is limited to 39 bytes. For the transmission of messages containing more than 39 bytes the message has to be split up in several packets. Due to the limited packet rate of the NEAN data link the overall transmission latency of a message increases with the number of NEAN packets to be used for the transfer. Every 39 bytes the figure presents a branch, because messages containing more than 39 bytes are assembled by smaller packets (e.g. a message of 48 bytes is assembled by one packet of 39 bytes and one packet of 9 bytes). This also means that new time slots have to be found for the transmission.

Parameter		**Results**	
		uplink	**downlink**
Average Data Transmission latency boundaries	min	427 ms* (3 bytes)	317 ms* (3 bytes)
	max	16 541 ms* (1020 bytes)	13 574 ms* (1020 bytes)
* extrapolated data			
Test Conditions			
Number of Users		2-3	2-3

Table 16: Extrapolated Transmission Latencies for message lengths up to 1020 Byte (NEAN)

6.2.2.3 Mode S

6.2.2.3.1 General

In the test plan it was foreseen to have extensive tests on the Mode S subnetwork on the Uplink and Downlink. Results were expected on various performance data of the subnetwork in both directions. But, due to serious problems of the used Mode S subnetwork components, only some of the planned trials could be finished. During the measurements performed on the subnetwork the radar station was all the time operating at its limits. Its experimental design and low performance do not allow to process Mode S target numbers as detected in the dense environment in Germany. Therefore, high target numbers in the coverage caused target losses, additionally to detected siting and transponder antenna problems,. Since the test tools were not designed to handle interrupts to the SVC's, the tests always had to be restarted, resulting in erroneous or incomplete test logs, which couldn't be analysed. Entire test had to be repeated, consuming a large amount of time. Nevertheless, target losses during a radar surveillance tracking are not unusual and should be handled by operational equipment without any problems. In addition to that, the data link equipment itself did not operate as required. Two major problems were identified in the T-ADLP software and one in the T-GDLP (see Appendix C). As there were no resources planned for corrective actions on the software, this situation caused the complete cancellation of the downlink laboratory tests.

With respect to the detected equipment deficiencies, the length of a whole test script and the possible packet transfer rates, all test scripts had to be split into individual, shorter ones to complete the remaining experiments on a much lower repetition rate.

The results should be reviewed with respect to the above mentioned equipment characteristics. The detected problems are not representative for the Mode S data link, operational equipment will be able to fulfil the requirements without any limitations.

6.2.2.3.2 Mode S Call Set-up Call Clearing Latencies

The measurements were performed using the DLTEs. The test results are shown in the following diagrams. For their review, the radar revolution time of 10 sec has to be taken into account.

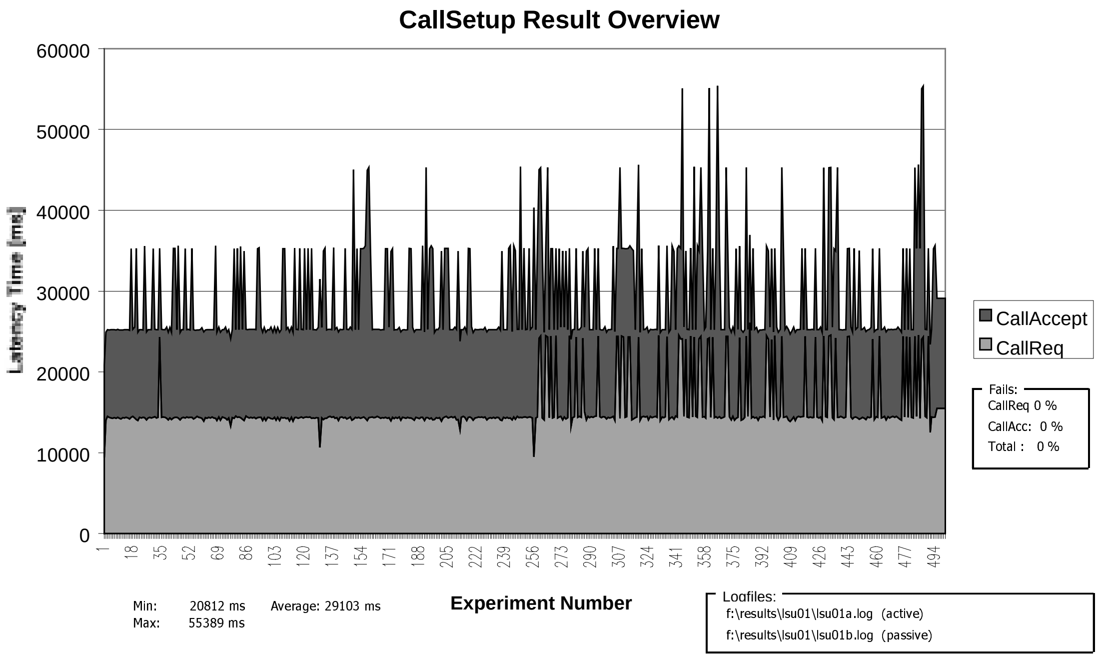

Figure 70: Measured Call Setup Latency (Mode S ground-initiated call)

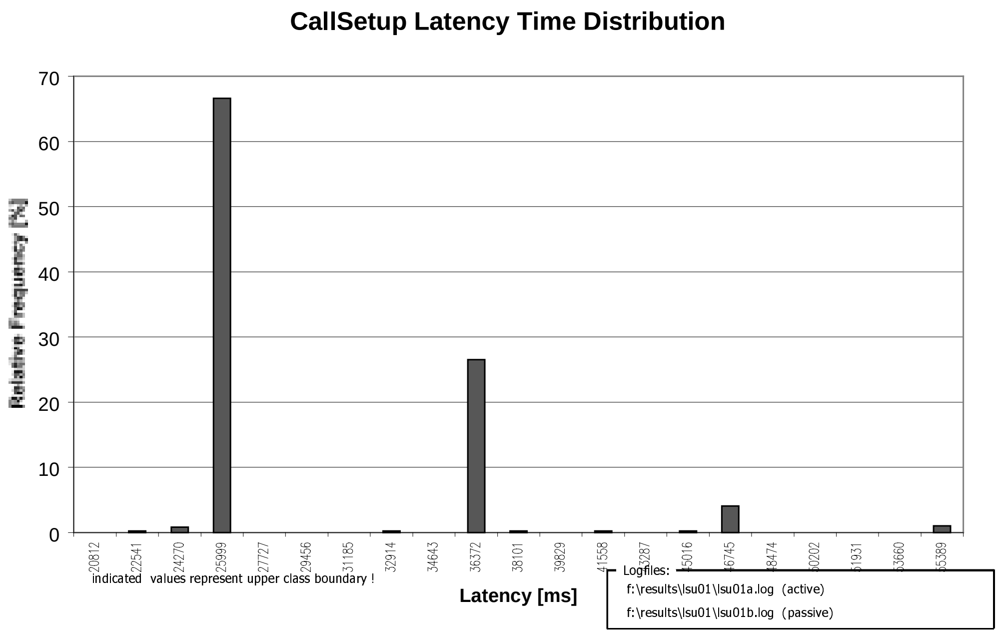

Figure 71: Call Setup Latency Distribution (Mode S ground-initiated call)

Observations	data link: Mode S		
direction: uplink	experiment ID: LSU01	figures: Figure 70 Figure 71	objectives: Call Request latencies

1	Figure 70 and Figure 71 show that the Call_Request latencies are in general almost constant over the time of the experiment. A ground-initiated Call_Request can be finished within 2 scans plus the time needed until the first beam dwell. This is characteristic for this type of radar. The new generation of operational radars will have the capability to finish transactions on a higher speed. The second part of the diagram shows an increase of the Call_Request latency time. Since the diagrams are assembled of different log files (see observation 3), a different behaviour of the equipment resulted in different curves. In this particular case the T-GDLP started to transmit Route packets in parallel to the Call_Request packets. This doubled the amount of transactions to one target, consuming more time to complete the transfer. Since the T-GDLP was reacting this way only one time during the experiments, the reason for this behaviour could not be found.
2	The downlink Call_Accept transfer is finished in most cases within one scan, but in much more cases the Call_Accept latency is higher than expected, shown by the peaks in the diagram. This is caused by the weak RF link between transponder and radar and the environmental conditions. In case the radar could not extract the packet in the first scan a second or third scan was needed to complete the transfer. The latency time increased then in 10 sec steps, caused by the antenna revolution duration.
3	Observations 1 and 2 only explain the case of a ground-initiated Call. Since the test always stopped after 128 repetitions, it had to be performed several times to complete. The exact reason for this behaviour could not be found (DLTE or T-GDLP). Due to an additional T-ADLP software error the air-initiated Call set-up test could not be performed (see Appendix C)

Parameter		**Results**	
		Ground-initiated	**Air-initiated**
Total call Set-up latency	min	20812 ms	-
	average	29103 ms	-
	95 %		-
	max	55389 ms	-
Test Conditions			
Traffic load	avg.	160	-

6.2.2.3.3 Mode S Transfer Rate Determination

Due to a T-GDLP software error, this test could not be performed (T-GDLP Flow Control Bug, see Annex C).

6.2.2.3.4 Mode S Data Transmission

Since there were no possibility to perform the Mode S transfer rate determination, measurements were taken to adapt the Mode S sub network to an appropriate packet rate for each individual test. This packet rate ensured that all data packets could be processed without filling up buffers within the T-GDLP and the Mode S radar, thus preventing a situation causing a T-GDLP crash (see Appendix C) and/or adding “buffer time” to the transactions. The test results are shown in the following diagrams.

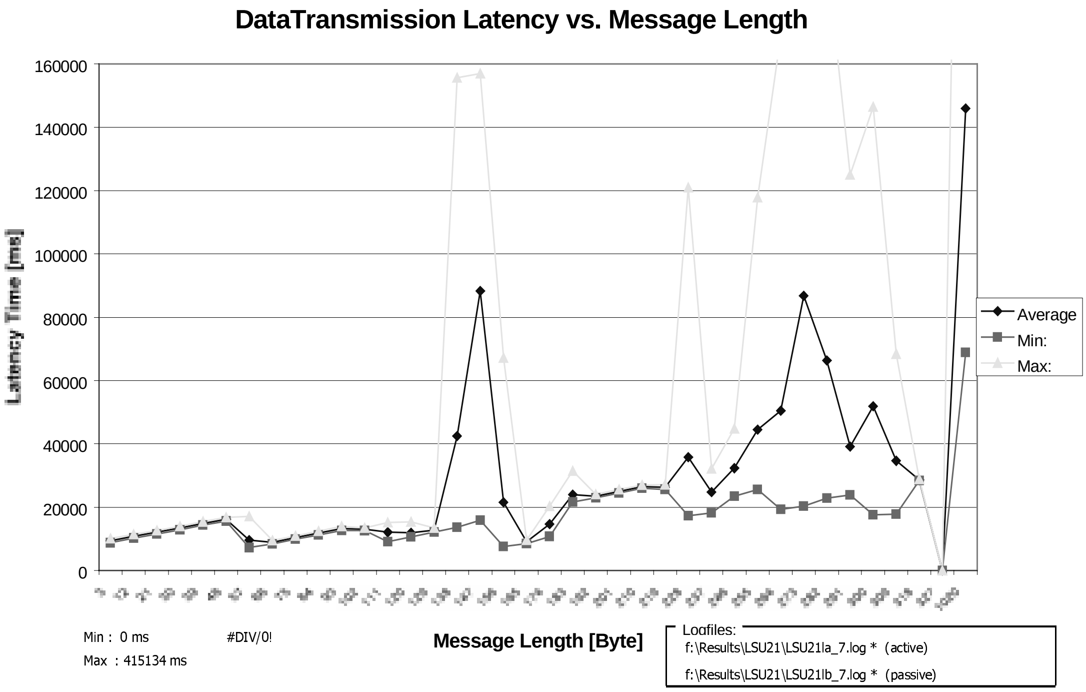

Figure 72: Mode S Data Link Layer Data Transmission Latency (uplink)

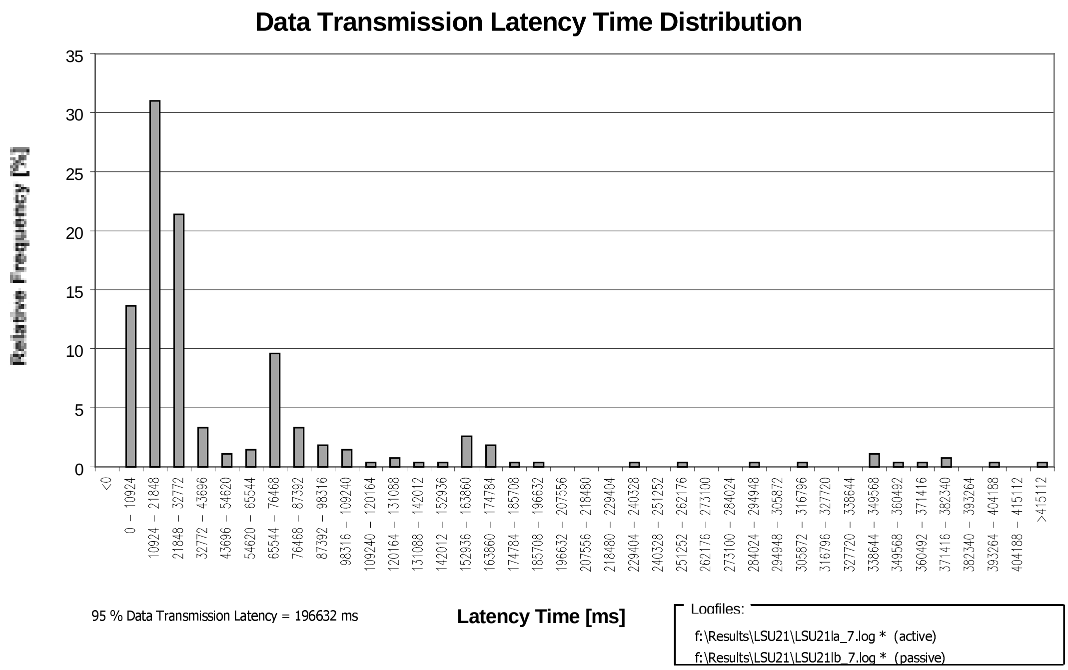

Figure 73: Mode S Data Link Layer Data Transmission Latency Distribution (uplink)

Observations	data link: Mode S		
direction: uplink	experiment ID: LSU21	figures: Figure 72	objectives: Data link data transmission latency, lost packets

1	Figure 72 shows that the transmission latency changes with the packet length and the time. The minimum curve is characteristic for this type of radar under optimal conditions. Depending on the message length, the radar has to transmit the data in linked SLMs or ELMs. The capability of the radar allows to send a linked Comm-A or an ELM (16 segments) in one scan. Data packets, requiring more than that will be distributed over several scans. An observed slightly increase of the transmission latency with the time is an artefact caused by the control of the message transmission times. The message sending interval is a multiple of the antenna revolution time. Due to the fact that the revolution time is not exactly 10 seconds, this time difference is added scan by scan to the data transmission time. In an operational implementation messages would be generated at random intervals, so that the fluctuation of a antenna revolution time would also be observed but the mean value would be half the radar revolution period.
2	Peaks in the latency time are caused by the RF and environmental conditions during the tests. The increased amount of data depending on the message length, force the radar to transmit the data in more than one ELM. In case an ELM transaction could not be finished within a scan, the data were kept in the T-GDLP buffer and sent after all other completed transmissions. If there were more of those cases during a message transmission, the data transmission latency increased rapidly to a very high value. The high average transmission latency time is the result of the high maximum value for those particular cases.
3	Packet losses were only caused by aircraft exits due to the weak RF link or by the test tool itself (too short packet interval), clearing the channel before the transaction has been completed.
4	Observations 1, 2 and 3 explain the case of uplink data transmissions. Due to a T-ADLP software error the downlink data transfer test could not be performed as required (see Appendix C).

Parameter		**Results**	
		Uplink	**Downlink**
Data transmission latency (all message lengths)	min	-	-
	average	-	-
	95%	-	-
	max	-	-

Test Conditions			
Packet interval (active DLTE)		between 30000 and 90000 ms (depending on the message length)	

6.2.2.4 AMSS

6.2.2.4.1 AMSS Call Setup Call Clearing Latencies

The AMSS Call Setup and Call Clearing Trials were performed with the DLTEs. The following diagrams present the results.

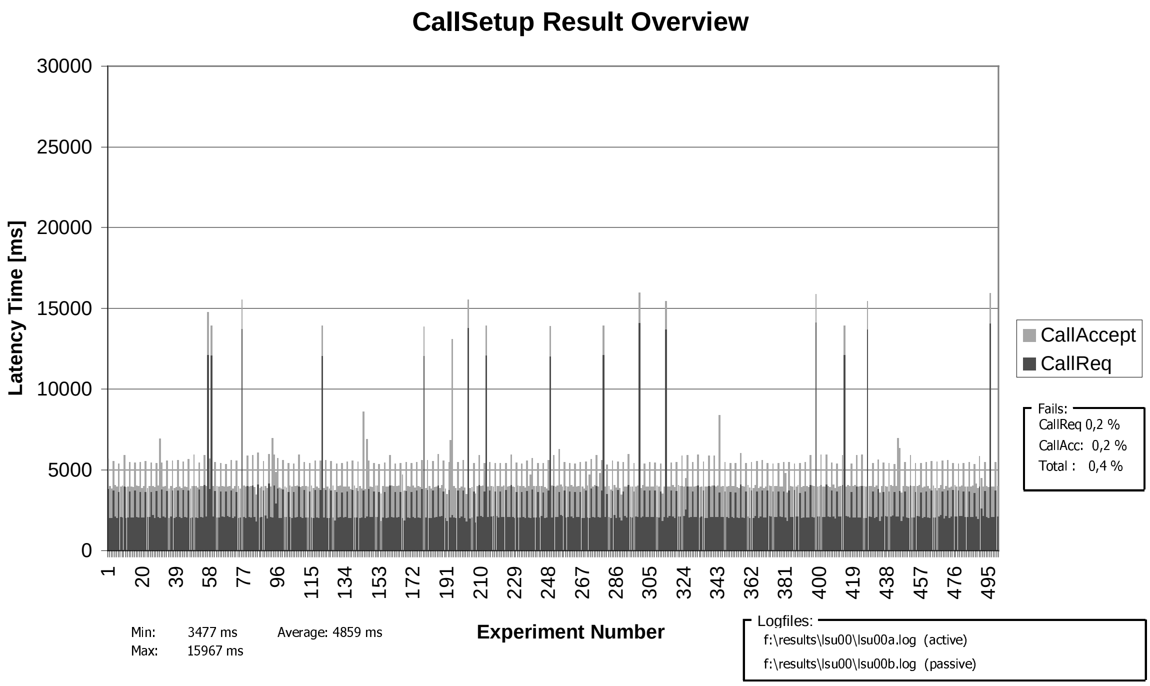

Figure 74: Measured ISO/IEC 8208 Call Setup Latency (AMSS ground-initiated call)

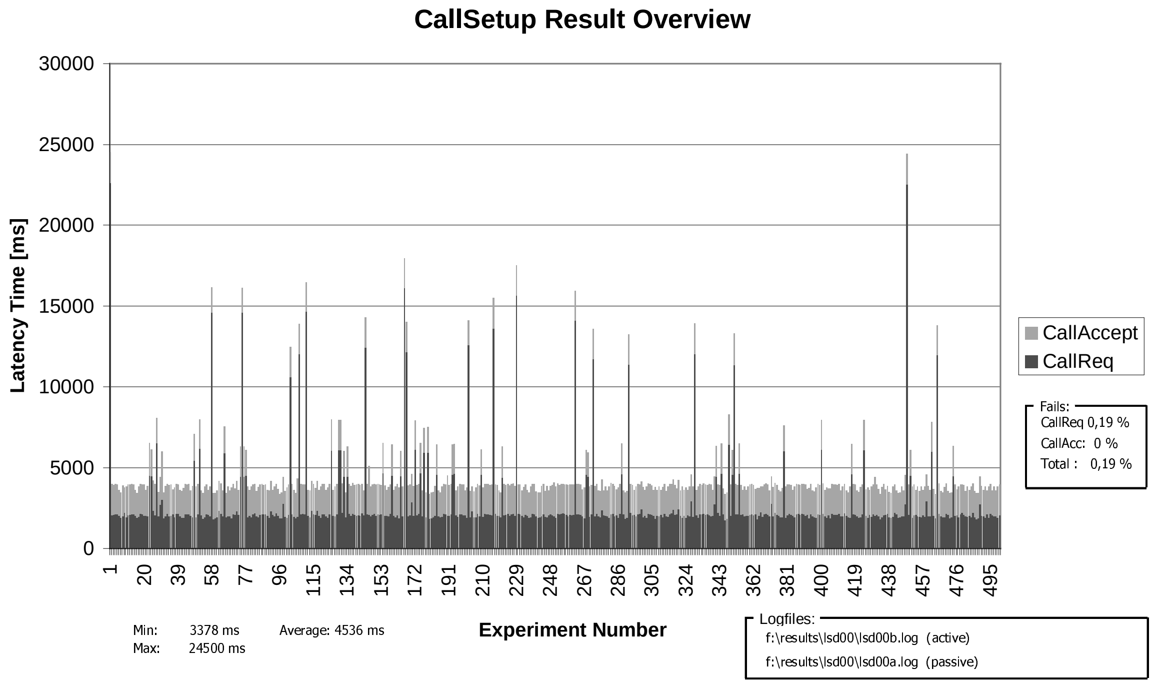

Figure 75: Measured ISO/IEC 8208 Call Setup Latency (AMSS air-initiated call)

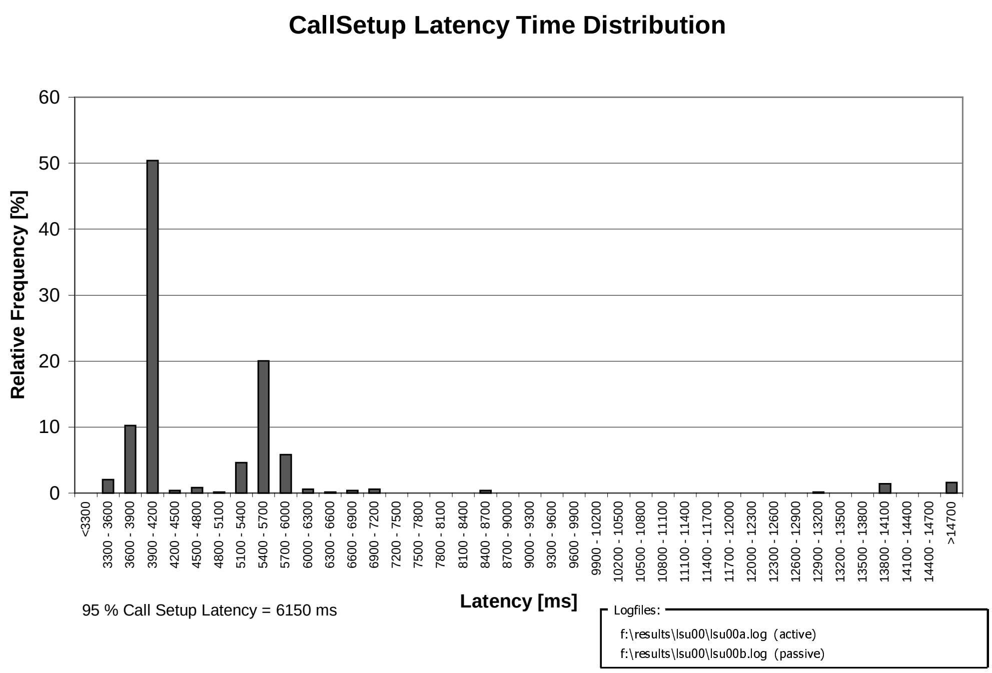

Figure 76: ISO/IEC 8208 Call Setup Latency Distribution (AMSS ground-initiated call)

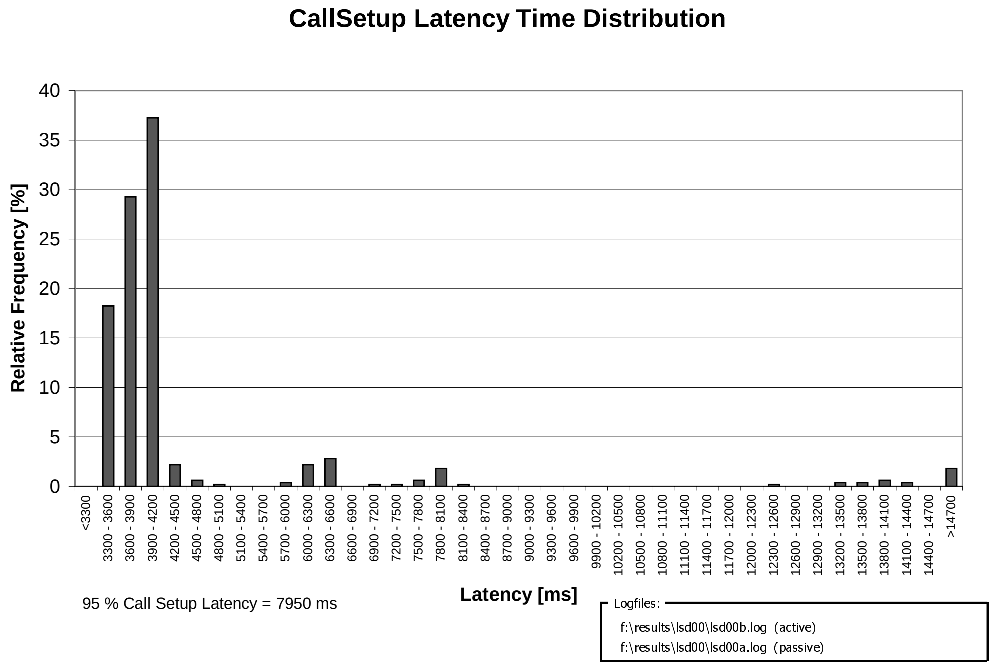

Figure 77: ISO/IEC 8208 Call Setup Latency Distribution (AMSS air-initiated call)

Observations	data link: AMSS		
direction: ground-initiated air-initiated	experiment ID: LSU00 LSD00	figures: Figure 74 - Figure 77	objectives: Call_Request Latencies

1	Figure 74 and Figure 75 show that the Call Setup latencies are in general almost constant over the time of the experiment, however significant exceptions which are about 10 s higher than the average call setup latency can be observed from time to time. The magnitude of the exceptions on the uplink suggests that in those cases an uplink packet is lost on the P channel, so that no PACK is sent by the AES. After tG1=9.3 s the GES sends a Request for Acknowledgement (RQA) packet upon which the AES responds by a PACK indicating that the entire message is to be re-transmitted because it only knows about the message after the RQA packet is received. On the downlink the situation is slightly more complex to understand. If a downlink Call request (sent via the R channel) is lost, then the GES would not send a RACK packet back to the AES. Without receiving a RACK the AES would resent the call request after between 7.9 and 9.4 s, so that the call setup transmission time is increased by that amount. Figure 77 shows Call setup times which fall into the area around 13 seconds and can be attributed to an R channel retransmission. However those call requests in the area around 6.3 s can not relate to lost downlink messages and a retransmission because the extra delay is to small. Perhaps the message was corrupted partially (one R channel slot overlapped with another AES R channel transmission so that the GES requested a retransmission). Since the GES received individual SUs from the Call Request SU set, it responds immediately by a RACK indicating lost SUs. Upon this the AES retransmits the lost SUs before the R-Channel Acknowledgement timed out as in case of a complete loss.
2	The majority of the Call Setup times is located in the shorter interval however there is also a significant amount of call set-up Latencies which are significantly longer. see 1
3	Uplink and downlink offer nearly the same average Call Setup Latency times. For the exchange of call Request and Call Clearing packets only rather short packets are to be exchanged. On the downlink the R channel is used for the short packets. The R channel has nearly the same properties as the P channel used on the uplink if no retransmission occurs.
4	

Parameter		**Results**	
		Ground-initiated	**Air-initiated**
Total Call Setup latency	min	3 500 ms	3 400 ms
	average	4 900 ms	4 500 ms
	95 %	6150 ms	7950 ms
	max	16 000 ms	25 000 ms
Test Conditions			
Data 3 users logged on		1	1

Observations	data link: AMSS				
direction: ground-initiated air-initiated	experiment ID: LSU00 LSD00	figures: Figure 74 - Figure 77		objectives: Call_Request Latencies	
Data 2 users logged on			174		173

Table 17: Call_Request Latencies (AMSS)

6.2.2.4.2 AMSS Transfer Rate Determination

The AMSS Transfer Rate Trials were performed with the DLTEs. The following diagrams present the results.

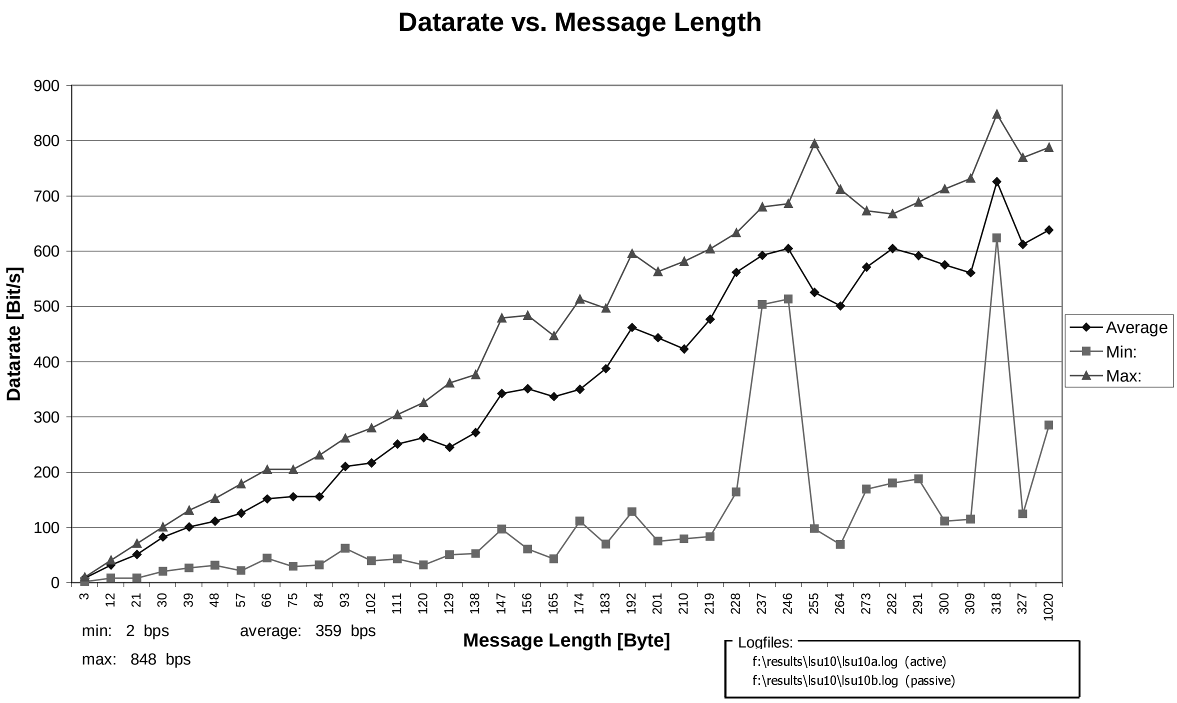

Figure 78: AMSS Data Link Data Rate vs. Message Length (uplink)

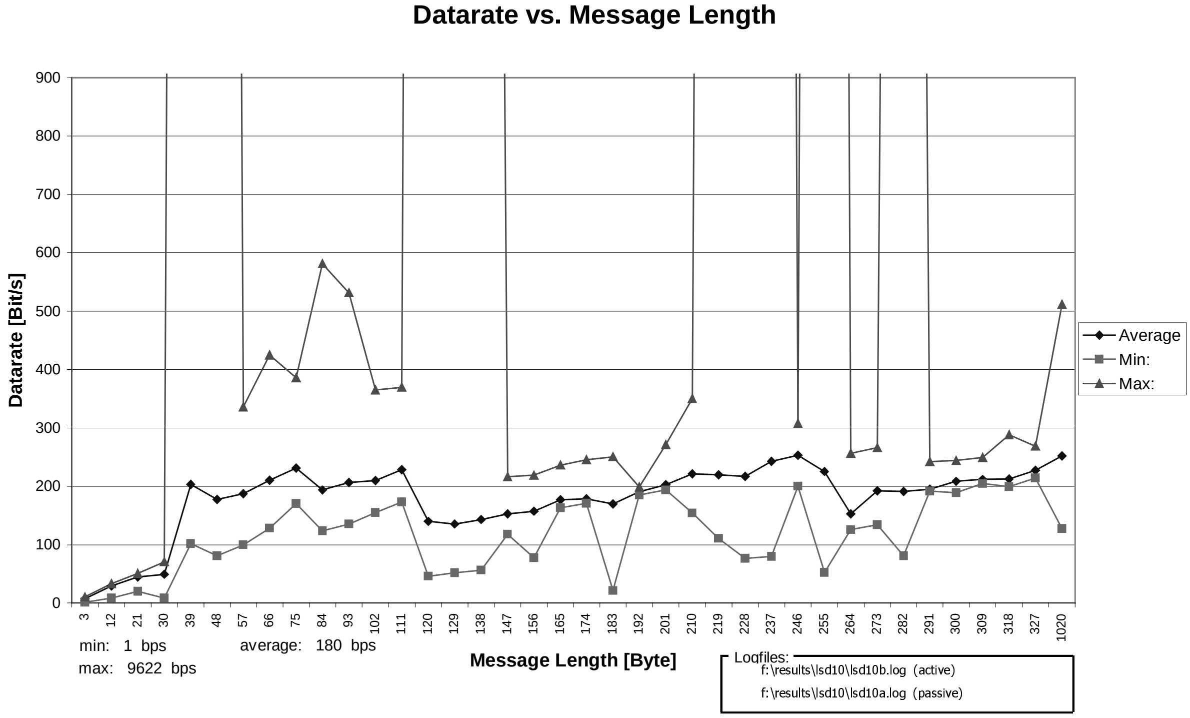

Figure 79: AMSS Data Link Layer Data Rate vs. Message Length (downlink)

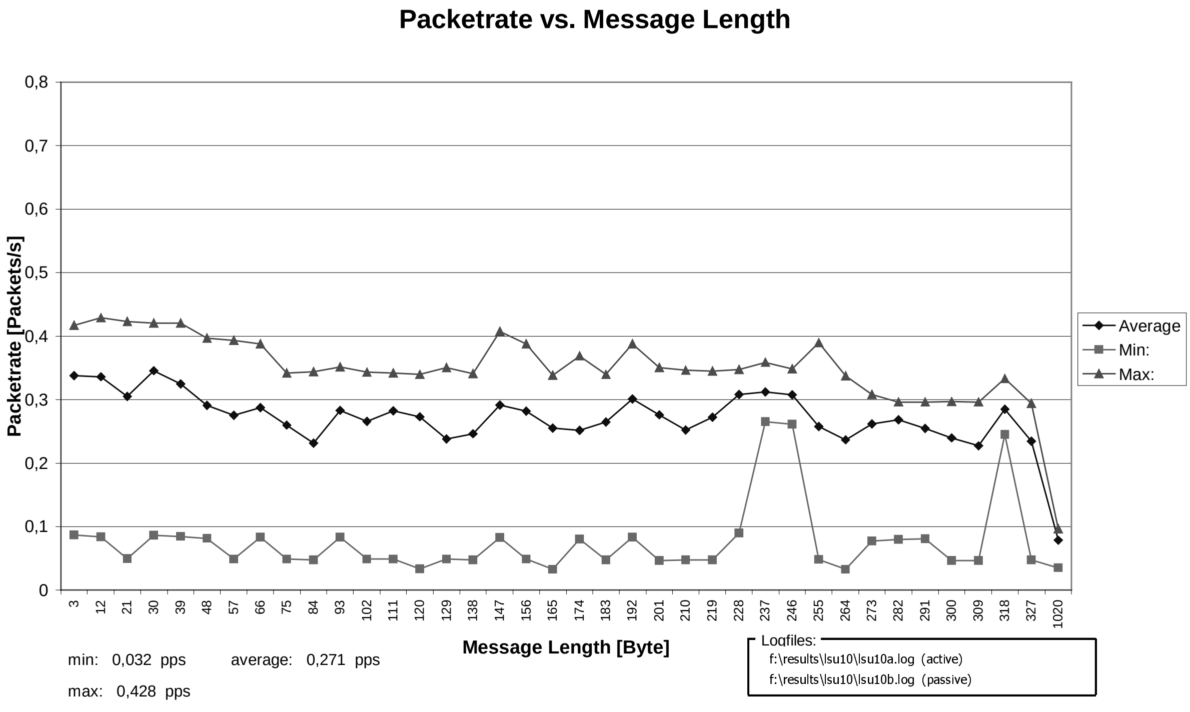

Figure 80: AMSS Data Link Packet Rate vs. Message Length (uplink)

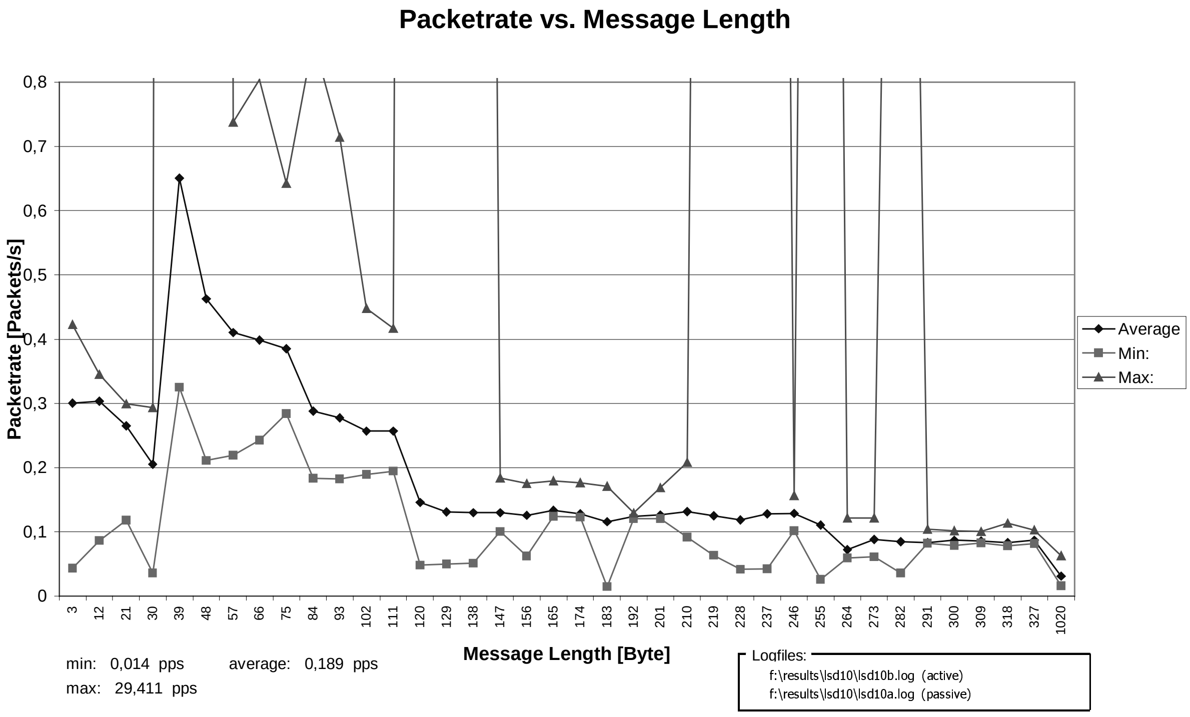

Figure 81: AMSS Data Link Packet Rate vs. Message Length (downlink)

Observations	data link: AMSS		
direction: uplink downlink	experiment ID: LSU10 LSD10	Figures: Figure 78 - Figure 81	objectives: Data link Data- and packet rates

1	On the uplink the data rate increases monotonic with the message length. At the same time the packet rate is almost constant or slightly decreases. On the uplink the AMSS data link is primarily limited by the packet rate. As the AMSS data link is limited in uplink-direction by the maximum packet rate (i.e. 0,27 packets per second) and not limited by its data rate, the overall transfer rates increases with the number of bits contained per packet.
2	The measurement results of Figure 79 and Figure 81 illustrate that the AMSS downlink is limited by a maximum data rate rather than a maximum packet rate. To understand the measurement results displayed in these figures the following explanation is given: A data stream with a constant data rate of 800 bps was used as input for the SDU. Due to the limitations of the AMSS downlink, this data stream could not be forwarded by the SDU at the same rate; rather data were queued in the SDU. Due to this overload condition the downlinked data were transmitted at the maximum possible data rate of the AMSS downlink channels, resulting in a more or less vertical data rate curve measured in Figure 79 (if the leaps are ignored which are explained later). This figure illustrates that this maximum data rate is about 50 bps in the R-channel and about 190 bps in the T-channel. Figure 79 also illustrates the sudden increase in the data rate for messages longer than 33 bytes which is caused by the switch-over from the R-channel to the more performant T-channel for messages exceeding a size of 33 bytes. The explanation for the second leap (for messages longer than 120 bytes) is given below. On the ground, the data packets were received at a constant data rate, i.e. the maximum downlink data rate, by the GES and forwarded at this rate to the ground test tool. The received data stream was sliced by the test tool into the sent packet sizes. As a consequence of the constant receiving data rate, the number of short packets received per time had to be inherently greater than the number of longer packets. This is illustrated in Figure 81 which shows for both channels, i.e. R-channel and T-channel, a distinct decrease of the packet rate in the case of increasing message sizes. Again the switch-over from the R-channel to the T-channel is clearly visible. Comparison of the absolute measurement values in Figure 79 and Figure 81 confirm the consistency of both graphs. For example, sending 48-bytes long packets over a channel with a maximum data rate of 190 bps (such as the T-channel) results in a packet rate of 0,49 packets/second in theory; this value is almost identical to the measured value in Figure 81. Sending 273-bytes long packets over a channel with a maximum data rate of 190 bps results in a packet rate of 0,086 packets/second. This theoretical value corresponds almost exactly with the measured value in Figure 81. The same consistency check can be made for the R-channel: For example, sending 30-bytes long packets over a channel with a maximum data rate of 50 bps (such as the R-channel) results in a packet rate of 0,2 packets/second in theory, which is exactly the measured value in Figure 81.
3	Packets of 120 bytes result in a lower data rate than shorter packets

Observations	data link: AMSS		
direction: uplink downlink	experiment ID: LSU10 LSD10	Figures: Figure 78 - Figure 81	objectives: Data link Data- and packet rates

The reason for this is that packets from 120 bytes onwards are transmitted as two individual LIDUs in the system which was investigated. Theoretically the T channel could transmit blocks up to 239 user data bytes in one single transaction. Since an acknowledgement for the transmitted packet needs to be awaited after each packet, the transmission interval is increased from 120 user data bytes onwards. This in turn results in a lower data rate.

Parameter		**Results**	
		Uplink	**downlink**
Data Rate	min	2 bps	1 bps
	average	359 bps	180 bps
	max	848 bps	9.622 bps
Packet rate	min	0,03 pps	0,01 pps
	average	0,27 pps	0,19 pps
	max	0,43 pps	29,41 pps
Test Conditions			
Data rate (active DLTE)		10000 bps	800 bps
Data 3 users logged on		1	1
Data 2 users logged on		189	175

Table 18: Data link Data- and packet rates (AMSS)

6.2.2.4.3 AMSS Data Transmission

The AMSS Data Transmission Trials were performed with the DLTEs. The following diagrams present the results.

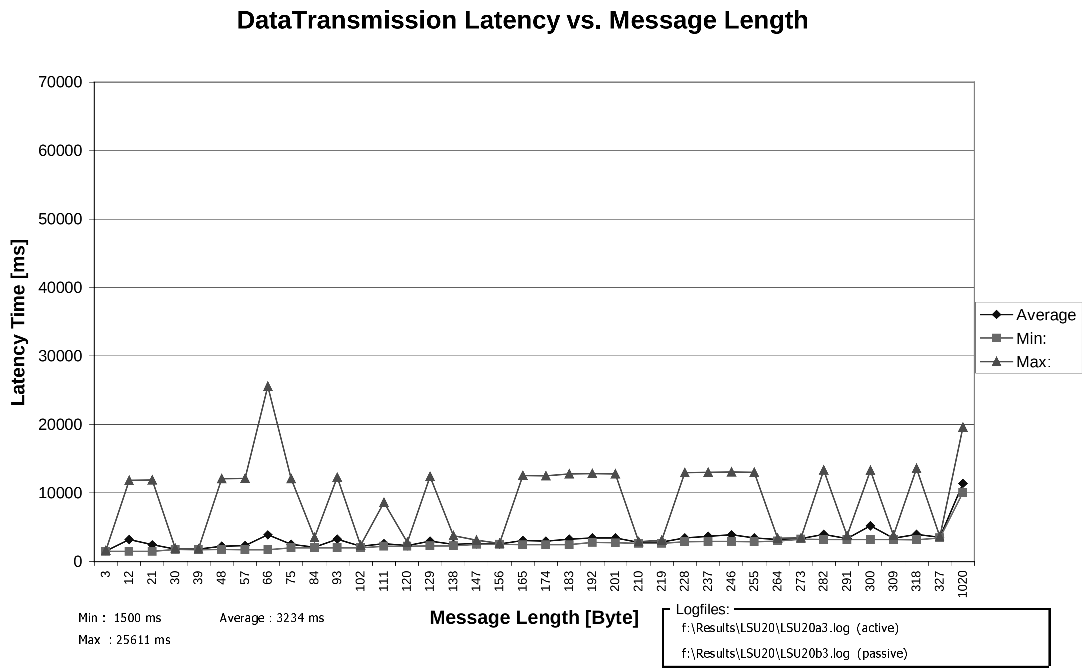

Figure 82: AMSS Data Link Layer Data Transmission Latency (uplink)

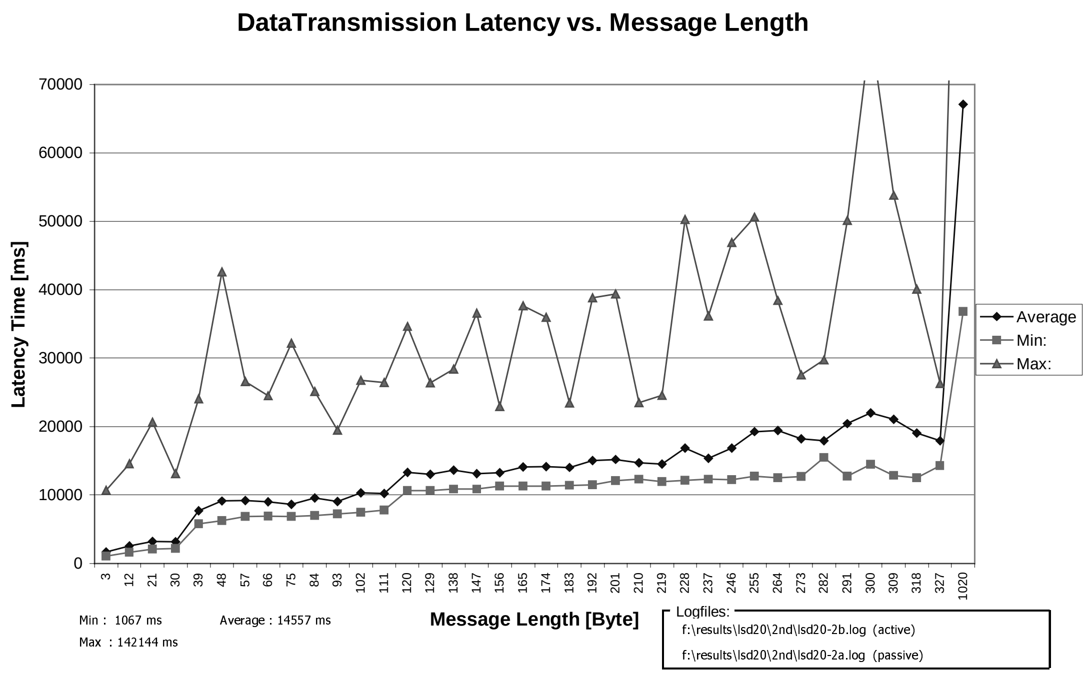

Figure 83: AMSS Data Link Layer Data Transmission Latency (downlink)

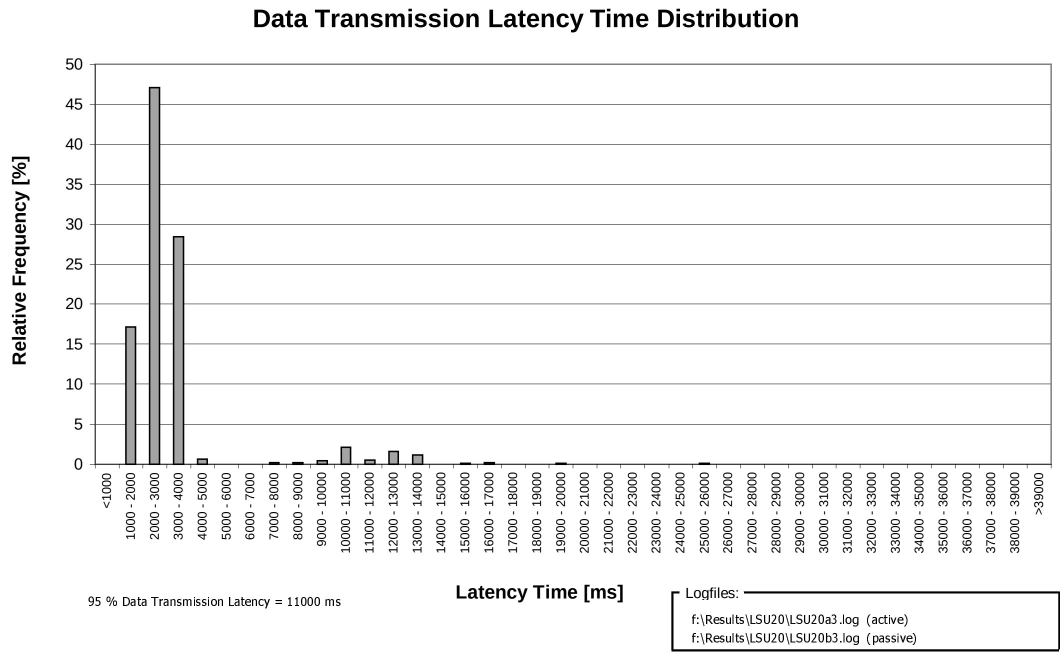

Figure 84 : AMSS Data Link Layer Data Transmission Latency Distribution (uplink)

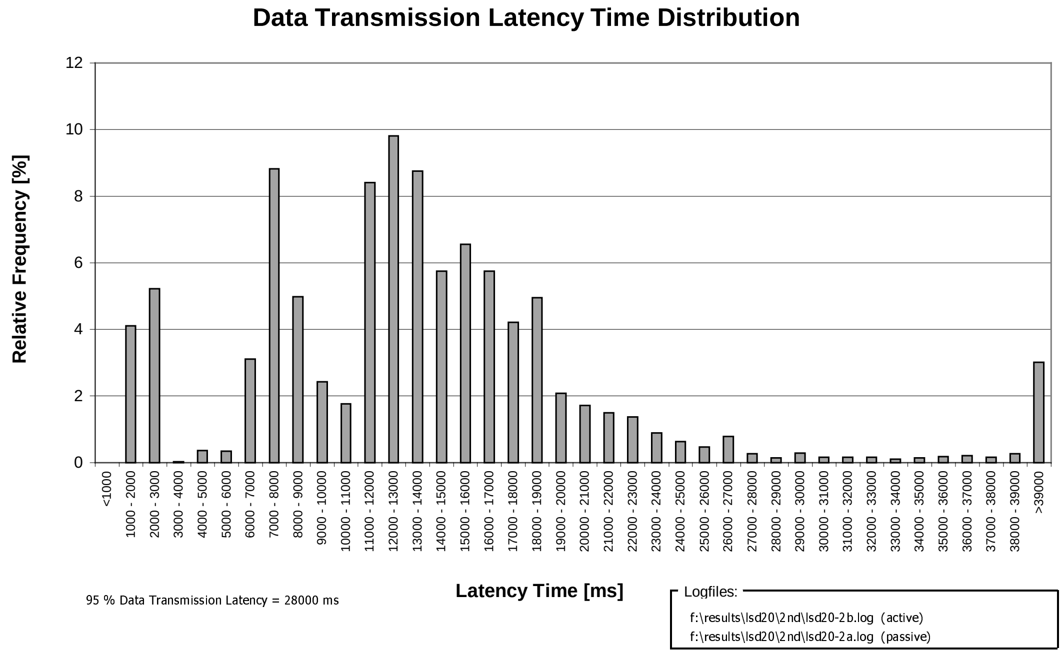

Figure 85: AMSS Data Link Layer Data Transmission Latency Distribution (downlink)

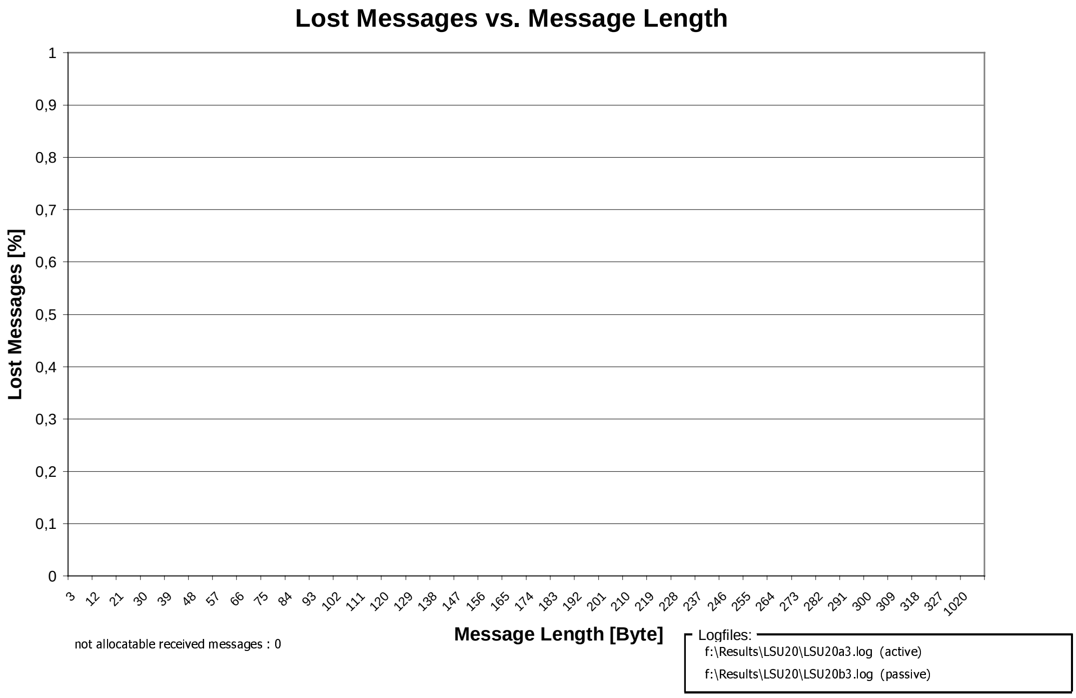

Figure 86: AMSS Data Link Layer Data Transmission Lost Messages (uplink)

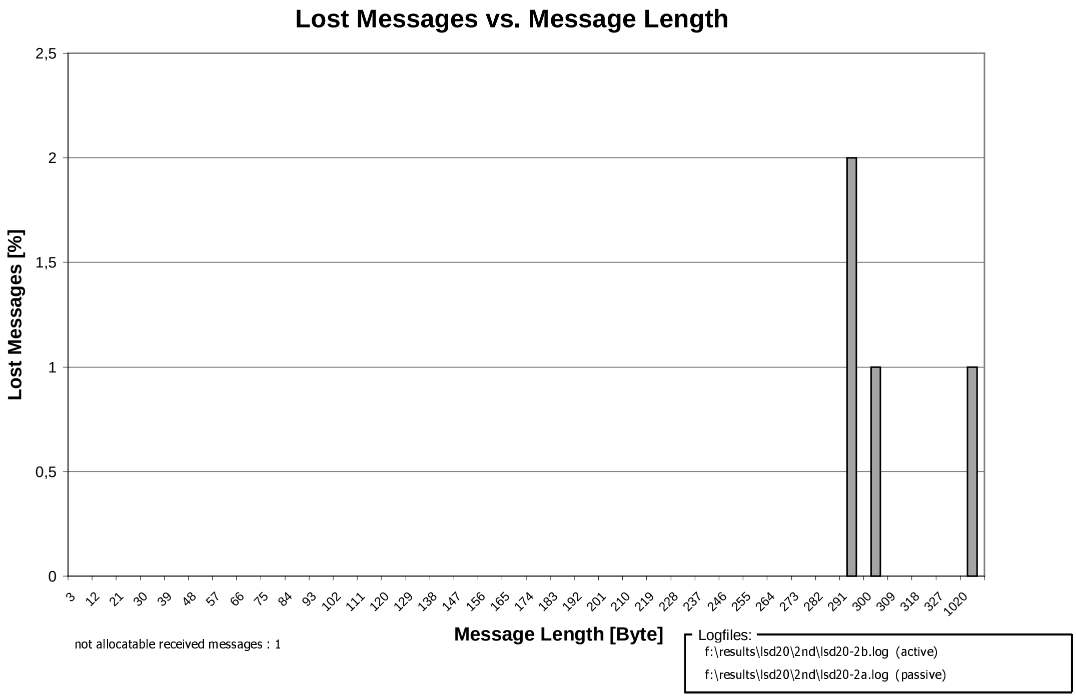

Figure 87: AMSS Data Link Layer Data Transmission Lost Messages (downlink)

Observations	data link: AMSS		
direction: uplink downlink	experiment ID: LSU20 LSD20	figures: Figure 82 - Figure 87	objectives: Data link data transmission latency, lost packets

1	On the uplink the data transmission latency increases slightly and linear with the message length. The transmission latency is more or less independent from the message length.
2	On the downlink the transmission latency for short packets up to 30 bytes is significantly lower than for longer messages. Short packets up to 33 bytes are transferred by the R-channel. The R-channel does not require a previous reservation so that it offers significantly lower transmission delays if it provides enough capacity.
3	On the uplink the maximum transmission latency values observed are about 10 seconds larger than the minimum values. It is assumed that in those cases the P-Channel Acknowledgement was not received by the GES, so that the GES resends the packet.
4	On the uplink the Transmission latency distribution shows that the majority of latency values lies in the area between 1000 and 4000 ms. It is assumed that a quite efficient transport mechanism on the uplink ensures a reliable transport of the data.
5	On the downlink the transmission latency distribution shows two transmission latency intervals in which the transmission latency is located (i.e. between 1000 ms - 2000 ms and another between 4000 ms and 27 000 ms) The interval between 1000 ms and 2000 ms relates to messages of less than 33 Byte length which were transmitted by the R-channel protocol. the other interval relates to messages transmitted by the T-channel protocol.
6.	On the uplink no lost packets were observed, while there were a few lost packets on the downlink. The lost packets on the downlink show that there is an obvious problem on the downlink. Aside from this it needs to be mentioned that the AMSS downlink data transmission experiment failed several times due to Clear_Requests from the AMSS link. The entire test run therefore had to be performed at first separately for packets shorter than 33 bytes and packets longer than 33 bytes. Again the long packet trials had to be restarted several times and the resulting log-files had to be combined after the test to obtain complete test log-files. There is obviously a significant problem in the AMSS downlink data link, which makes it unreliable.
7.	On the downlink one message was received which could not be related to a sent message. A detailed investigation showed that the last packet of an M-bit sequence was lost as well as the initial packets of the successive M-bit sequence, so that the packets of the successive M-bit sequence were appended to the first sequence. This led to the delivery of an artificial message. This fact shows that M-Bit transfers need to be used very carefully and that received message need to be checked for integrity by the next higher layer.

Parameter		**Results**

Observations	data link: AMSS		
direction: uplink downlink	experiment ID: LSU20 LSD20	figures: Figure 82 - Figure 87	objectives: Data link data transmission latency, lost packets

		Uplink	**downlink**
Data Transmission Latency (all message lengths)	min	1 500 ms	1 000 ms
	average	3 200 ms	14 600 ms
	95 %	11 000 ms	28 000 ms
	max	26 000 ms	142 000 ms
Average Data Transmission latency boundaries	min	1 573 ms (3 Byte)	1 673 ms (3 Byte)
	max	11 401 ms (1020 Byte)	67 111 (1020 Byte)
Test Conditions			
packet interval (active DLTE)		15000 ms	15000 ms

Table 19: Data link data transmission latency, lost packets (AMSS)

6.3 Flight Trials

The flight trials were performed to obtain any parameter changes between the laboratory trial results and real flight operation. In contrast to the laboratory trials not only the dependency of the transmission latency versus the message length was derived but also diagrams showing:

- the transmission latency versus the flight time and
- the lost messages versus the flight time.

By means of these additional diagrams any correlation between flight manoeuvres and observed problems could be analysed. In support of this the flight track was recorded by a data recorder onboard based on GPS and IRS position and attitude reports. In addition the ADS-B reports of the NEAN transponder were recorded. The derived flight tracks are shown for all flights.

The trials aircraft, a Cessna Citation business jet operated by NLR, performed a number of manoeuvres representative of normal flight operation. The aircraft was equipped with an AMSS AES (Honeywell / RACAL) with a low gain antenna, a Mode S Transponder (TRT) - ADLP (NLR) set with a diversity antenna installation and a NEAN Transponder (GP&C Sweden AB) with a combined GPS/VHF antenna on top of the fuselage. For the NEAN trials it was initially foreseen to use a newer R3 Transponder but it turned out that the performance of it in terms of range was so poor that the transponder was replaced by an older R2 Transponder for the actual flight trials. The airborne side of the trials equipment was complemented by a CODECAT DLTE which was installed on the aircraft to record the output of the data links and to stimulate them. On the ground the GES in Aussaguel was used for the AMSS flight trials, the experimental SSR Mode S Radar in Götzenhain was used for the Mode S flight trials and a T3 NEAN Transponder located in Frankfurt was used as the NEAN ground station for the NEAN flight trials.

The flights were performed in the Frankfurt area. The airport base was located in Hahn which is located about 60 nm west of Frankfurt. The flights were performed in a way compatible with the current air traffic and therefore resulted in different flight tracks for the individual flights.

The time synchronisation of the air and ground DLTEs was implemented by DCF 77 radio clocks. The airborne DLTE did however not receive the DCF signal properly during the flights and was therefore synchronised with DCF 77 only prior to the test flight and was then set to crystal operation during the flight. During the evaluation of the collected measurement data of the flight trials it was discovered that the time logged onboard the aircraft sometimes had an error of precisely 1 s, while the millisecond values were correct. This was attributed to a hardware problem of the aircraft DLTE (perhaps a loose radio clock card). Fortunately time checks were performed with Voice Communication during the flights so that any discrepancy between airborne and ground clocks was detected and recorded. The airborne logging times in the logfiles were accordingly corrected prior to the evaluation. On the AMSS uplink trial flight the time of the DLTE clock was even totally reset to zero when the DLTE was switched on after takeoff so that a large discrepancy between air and ground time was observed. Fortunately the clock continued to run normally so that only a constant offset had to be added to all times stored in the airborne logfile. The offset was obtained by the recorded radio checks.

Due to safety precaution (electromagnetic compatibility between the trials installation and the aircraft), the test equipment had to be kept off during takeoff and landing in case of poor weather conditions (which was the case in three of six times). Therefore test results for takeoff and landing could only be obtained for the NEAN data link, when the aircraft landed in Frankfurt, and for the AMSS uplink trial. All other flights did not deliver any data for the takeoff and landing in Hahn.

Table 20 provides an overview over all flight trials, the data link tested and the times of the first and last message stored in the individual logfiles generated during the flights. As all times were recorded in CET while the flight track was in UTC, the times are also indicated in UTC.

Table 20 does also list the message lengths contained in the individual logfiles.

Date	Trial	ID	Logfile Start (CET)	Logfile End (CET)	Logfile Start (UTC)	Logfile End (UTC)	Message lengths of related Script files
12.01.00	AMSS	FSD10	10:41:42	10:51:53	09:41:42	09:51:53	3 - 30 Bytes
	downlink		10:55:31	11:36:33	09:55:31	10:36:33	39-327 Bytes
			11:39:04	11:48:51	10:39:04	10:48:51	3-30 Bytes
			11:51:20	12:01:12	10:51:20	11:01:12	1020 Bytes
			12:06:31	12:47:34	11:06:31	11:47:34	39 - 327 Bytes
			12:50:07	12:59:53	11:50:07	11:59:53	3 - 30 Bytes
19.01.00	Mode S	FSU11	10:44:16	11:03:16	09:44:16	10:03:16	3-174 Bytes
	uplink		11:07:06	11:23:06	10:07:06	10:23:06	183- 327 Bytes
			11:25:05	11:41:05	10:25:05	10:41:05	183- 327 Bytes
			11:49:06	11:53:06	10:49:06	10:53:06	1020 Bytes
			12:01:01	12:13:03	11:01:01	11:13:03	1020 Bytes
			12:18:39	12:37:39	11:18:39	11:37:39	3 - 174 Bytes
			12:39:37	12:52:37	11:39:37	11:52:37	3 - 174 Bytes
19.01.00	Mode S	FSD11	15:32:45	15:54:05	14:32:45	14:54:05	3 - 174 Bytes
	downlink		16:11:42	16:12:42	15:1142	15:12:42	183 - 327 Bytes
			16:19:06	16:24:06	15:19:06	15:24:06	3 -174 Bytes
			16:44:14	16:47:14	15:44:14	15:47:14	183 -327 Bytes
20.01.00	NEAN R2	FSD12	10:18:05	11:38:09	09:18:05	10:38:09	3 - 39 Bytes
	downlink		11:38:10	12:21:03	10:38:10	11:21:03	3 - 39 Bytes
20.01.00	NEAN R2	FSU12	15:13:36	16:35:15	14:13:36	15:35:15	3 - 39 Bytes
	uplink		16:35:16	16:40:50	15:35:16	15:40:50	3 - 39 Bytes
21.01.00	AMSS	FSU10	11:13:11	12:03:37	10:13:11	11:03:37	3 - 327 Bytes
	uplink		12:06:42	12:24:07	11:06:42	11:24:07	1020 Bytes
			12:37:02	13:26:54	11:37:02	12:26:54	3 - 327 Bytes
			13:28:59	13:45:30	12:28:59	12:45:30	3 - 327 Bytes

Table 20: Flight Trial Overview

The following sections describe the flight trials performed for the individual data links by means of the flight tracks and the evaluation results.

6.3.1 NEAN Flight Trials

6.3.1.1 NEAN Uplink Flight Trial

The NEAN uplink flight trial was performed on the 20th January 2000. The flight began at 14:10 UTC and ended 15:45 UTC. It included takeoff and climb, several course changes, a short holding around 15:00 UTC, a low approach over Frankfurt airport and an approach and landing back in Hahn (HAN). The related flight track is shown in Figure 88 and Figure 89. Those segments where more than 10 % message losses were observed are indicated so that the influence of the distance from the NEAN ground station can be visualised.

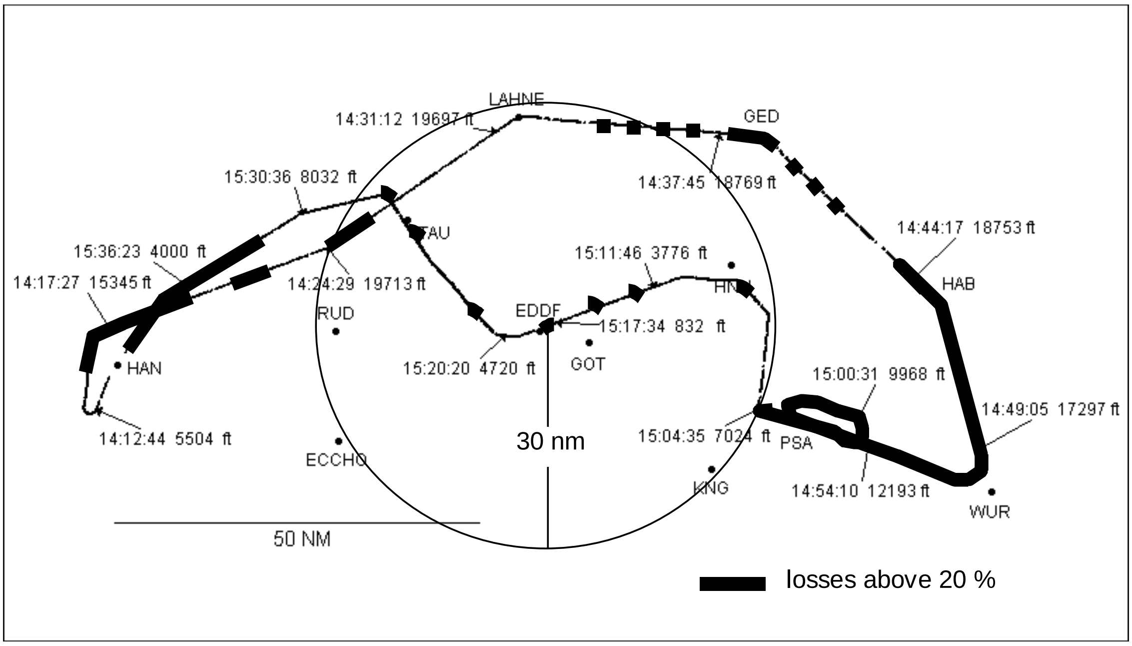

Figure 88: NEAN uplink Trial Flight Track

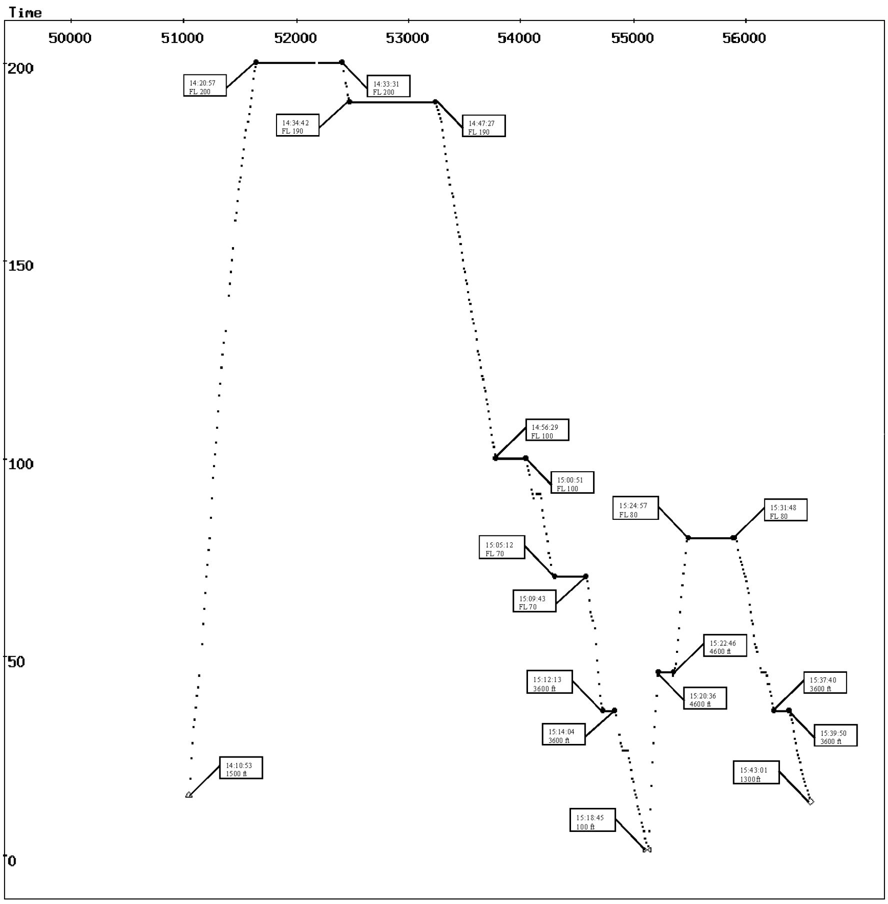

Figure 89: NEAN uplink Trial Flight Track (altitude)

The results of the NEAN uplink trial flight are depicted in the diagrams below.

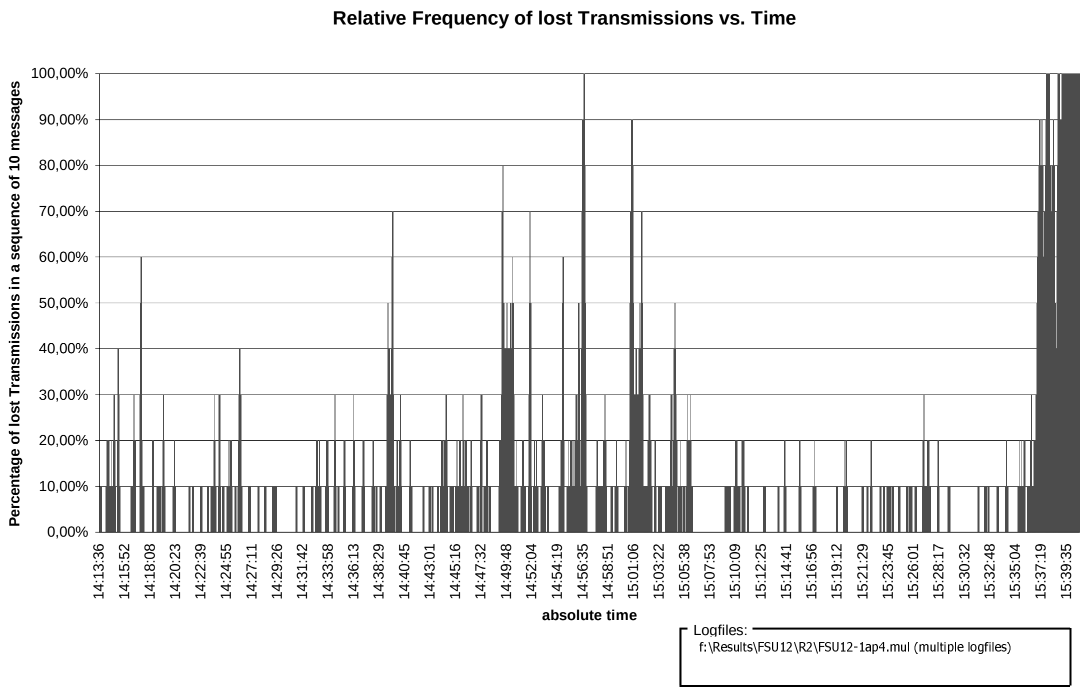

Figure 90: Percentage of lost Messages versus absolute Time (NEAN uplink Flight Trial)

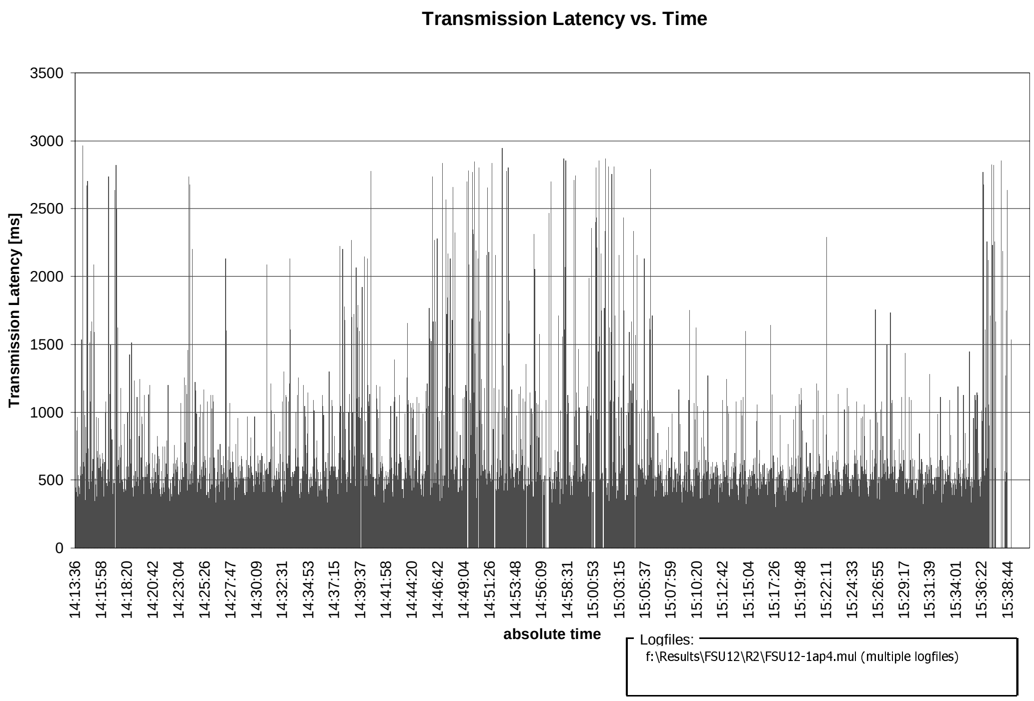

Figure 91: Data Transmission Latency versus absolute Time (NEAN uplink Flight Trial)

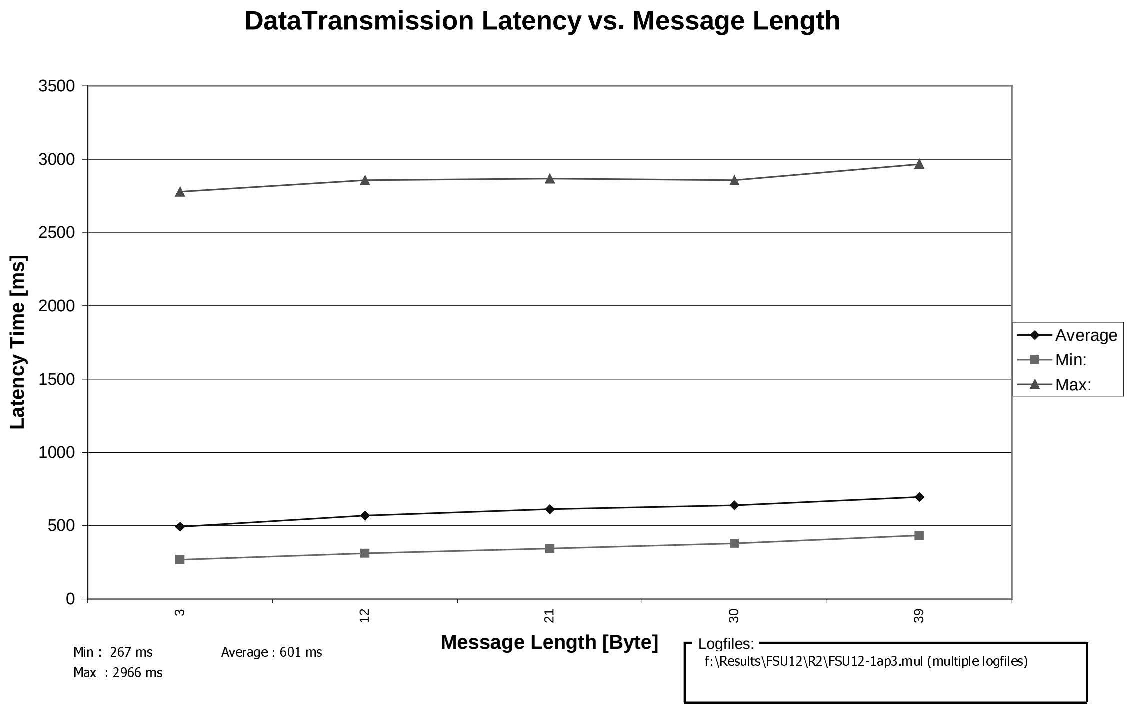

Figure 92: Data Transmission Latency versus message length (NEAN uplink Flight Trial)

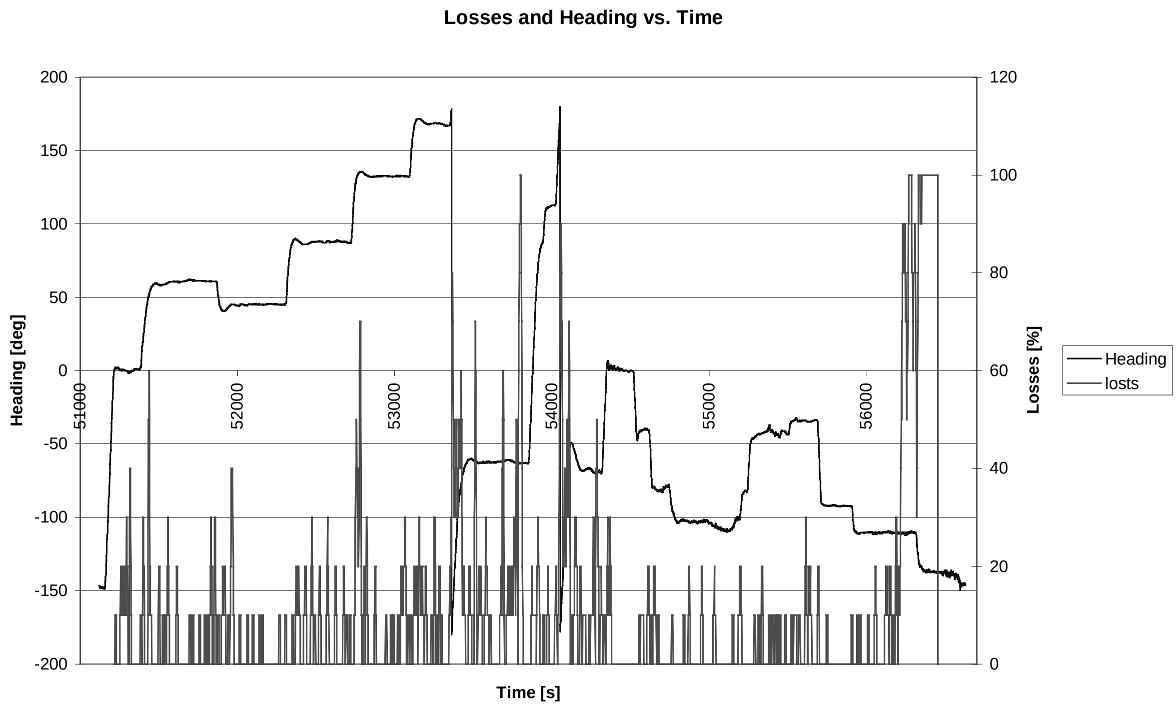

Figure 93: Losses and Heading versus time of flight (NEAN uplink flight trial)

Observations	data link: NEAN		
direction: uplink	experiment ID: FSU12	figures: Figure 88 - Figure 93	objectives: Data link data transmission in flight

1. A large number of lost messages is observed as depicted by Figure 90 during the flight. There is an increase between 14:13 and 14:20, between 14:33 and 15:05 and from 15:35 onwards.

   An analysis of those areas of the flight track (Figure 88) which show increased percentage of losses shows that they primarily lie outside of a 30 nm ring around the ground station. The increased loss rate is certainly attributed to the reduced signal to noise ratio in larger distances so that messages are no more properly received and finally lost. It should be noted that the NEAN protocol already makes precautions to retransmit a message if an acknowledgement is not received so that several messages have already been lost when finally a lost message is observed.

   In any case the successful transfer of messages is still possible even up to the maximum distance of the flight from the NEAN ground station of about 60 nm, however only with a relatively high percentage of lost messages. Only during descend and landing in Hahn there seem to have been serious problems so that more than 10 successive messages were lost, leading to loss percentages of up to 100 %. The amount of lost messages consumes a considerable amount of channel extra capacity since messages need to be retransmitted several times. In general the number of retries goes up to 3 so that under worst case conditions 3 times the channel capacity is required.

   One adverse factor did additionally contribute to the loss rates. The VHF antenna of the NEAN transponder was mounted on top of the fuselage as a combined GPS - VHF antenna. This lead to frequent shielding of the antenna by the fuselage. Figure 93 shows that they generally coincide with changes of the heading while the aircraft had particular roll and pitch angles which caused a shielding of the top antenna.
   To prevent this shielding effect the VHF antenna should at least be mounted below the fuselage where it has a better vision of the ground station in flight. It is expected that an antenna mounting below the fuselage would already significantly improve the behaviour.
   As manoeuvring is only performed during short periods of the flight there should be sufficient time foreseen in the NEAN retransmission concept to ensure that a message can still be delivered after a manoeuvring interval is finished so that messages are not lost during a manoeuvring but only delivered later. Currently retries are performed within an interval of only 600 - 800 ms with up to 3 retransmissions at maximum. This only leads to an interval of not much more than 3 seconds during which a message can be delivered. Short retransmission intervals are reasonable for short interference intervals, however the manoeuvring intervals should perhaps also be respected in future upgrades of the NEAN project so that a message is again delivered after the loss of contact is over.
2. The transmission latency (Figure 91) shows increased values when the distance between the NEAN ground station and the aircraft is high and can be correlated to the observation 1 above.

   This increase is also caused by the decreased signal/noise ratio. As mentioned in

Observations	data link: NEAN		
direction: uplink	experiment ID: FSU12	figures: Figure 88 - Figure 93	objectives: Data link data transmission in flight

1. above more messages are lost in those areas. A lost message is noticed by the sending ground station as the acknowledgement is not received within a certain time interval. In such case the lost message is retransmitted. The retransmission process adds some extra time until the message is finally delivered, so that the transmission latency is increased if messages are lost.

3. The data transmission latency average and maximum values show an increase of the transmission latencies compared to the laboratory trials up to about 10% for the averages and about 20 % for the maximum transmission latency. (see Figure 92) The transmission latency still stays below 3 000 ms even under realistic flight conditions. The shortest transmission latency time measured is almost similar to that of the laboratory trials. (see values in table below)

   The minimum times measured represent those cases in which optimal transmission conditions existed (i.e. short distance between aircraft and ground station). No retry was required so that only the basic processing time is involved as in the laboratory in case of optimally received messages.

   The maximum times are further increased in comparison to the laboratory trials since one additional retry (adding between 600 and 800 ms) is required to compensate the increased loss probability in case of the greater distances.

   The average value and the 95 % value of the flight trials are both increased as a result of the increased maximum.

4. The result for the data transmission latency as a function of the message length (Figure 92) is almost similar to that of the laboratory trials despite from the maximum value, which is slightly increased.

   No significant difference exists between laboratory and flight trial results despite the increased maximum due to one more retry in case of larger distances.

5. As shown in the evaluation of the NEAN downlink results below, the downlink has significantly better properties.

   It can be expected that a properly set up operational system can at least achieve the performance measured on the downlink also on the uplink.

Parameter		**Results**	
		Flight trial	**Laboratory**
Data Transmission Latency (all message lengths)	min	267 ms	256 ms
	average	601 ms	525 ms
	95 %	1 261 ms	1 030 ms
	max	2 966 ms	2 222 ms
Distance of low loss probability		~ 30 nm	-

Table 21: Data link data transmission in flight (NEAN uplink)

6.3.1.2 NEAN Downlink Flight Trial

The NEAN downlink flight trial was performed on the 20th January 2000. The flight began at 09:00 UTC and ended 11:25 UTC. It included start and climb, several course changes, a landing and taxiing in Frankfurt, a holding at about 10:50 UTC and an approach and landing back in Hahn (HAN). This flight also included an approach, landing, taxiing and takeoff at the Frankfurt airport. The taxiing is not visible in the diagram. The related flight track is shown in Figure 94 and Figure 95. Those segments where more than 10 % message losses were experienced are indicated so that the influence of the distance from the NEAN ground station can be visualised.

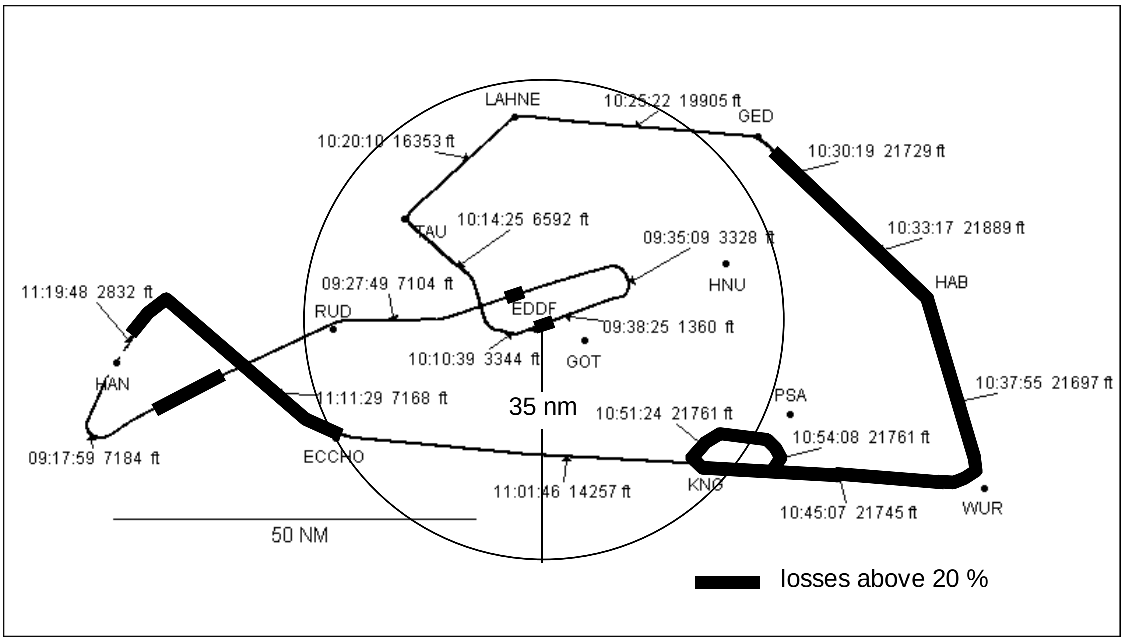

Figure 94: NEAN downlink Trial Flight Track

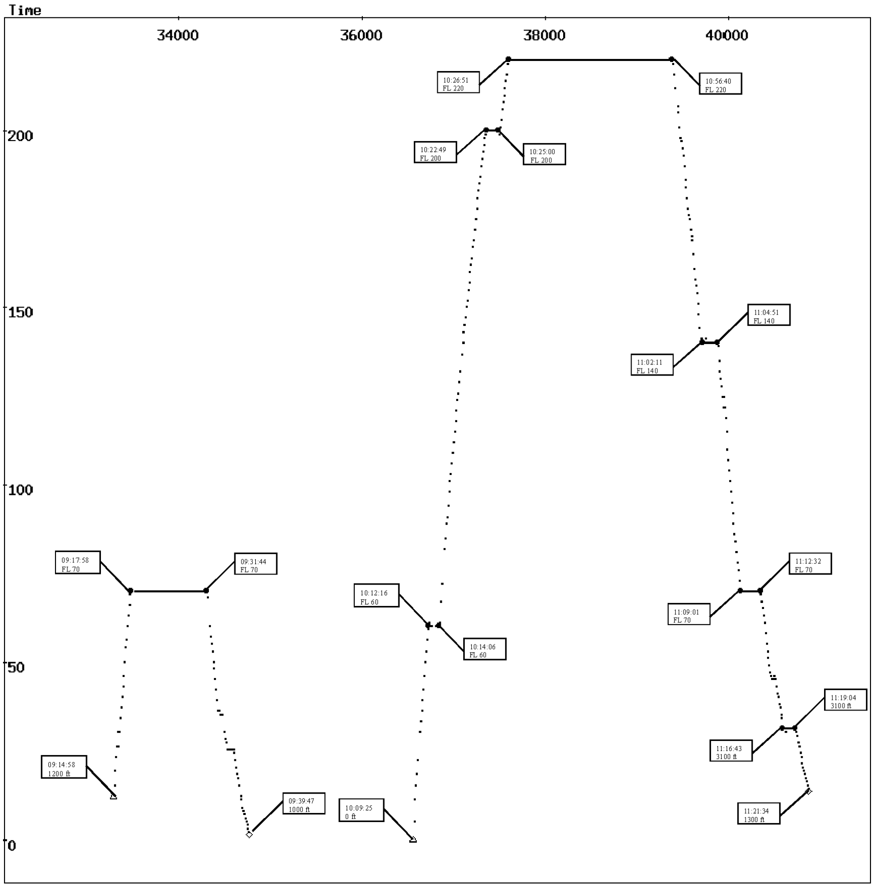

Figure 95: NEAN downlink Trial Flight Track (altitude)

The test results of the NEAN downlink flight trial are shown in the diagrams below.

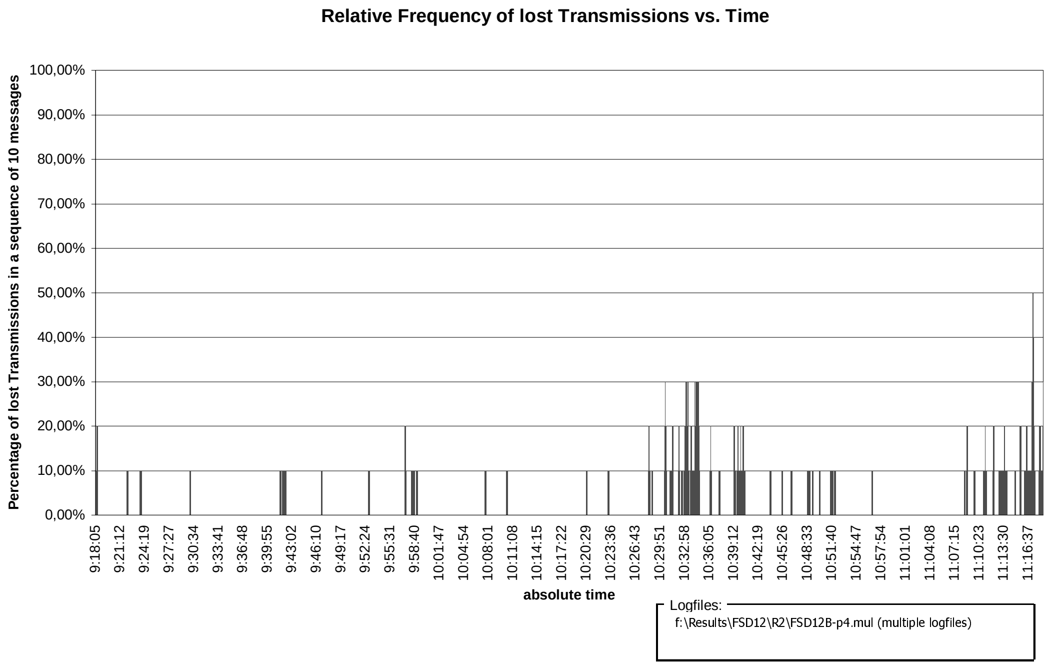

Figure 96: Percentage of lost Messages versus absolute Time (NEAN downlink Flight Trial)

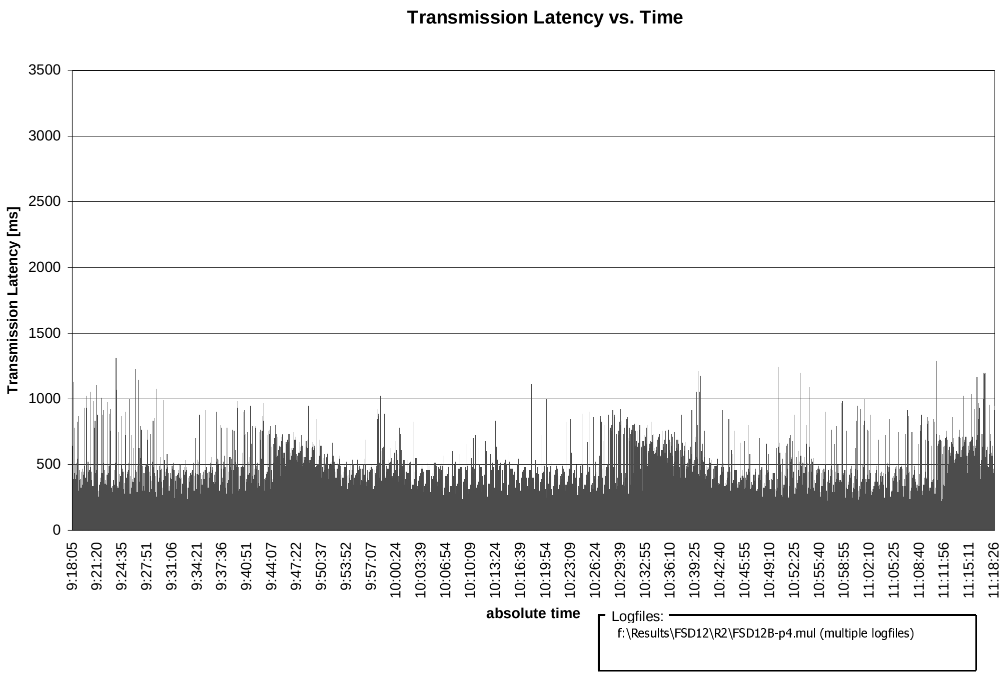

Figure 97: Data Transmission Latency versus absolute Time (NEAN downlink Flight Trial)

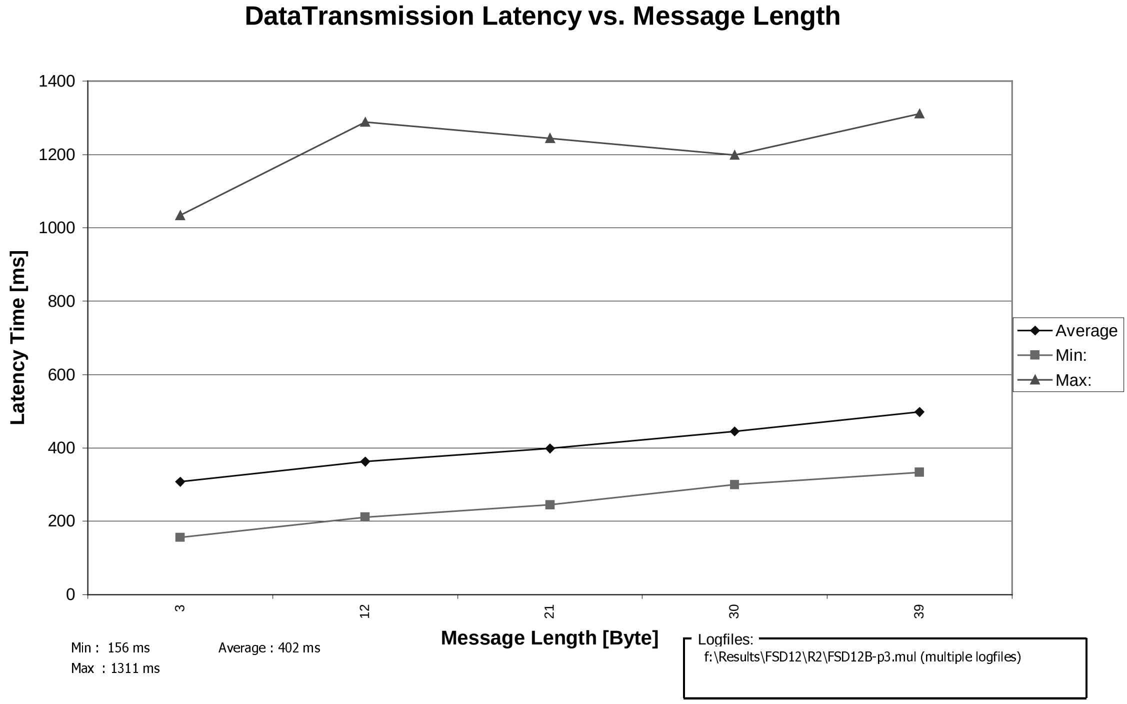

Figure 98: Data Transmission Latency versus Message Length (NEAN downlink Flight Trial)

Observations	data link: NEAN		
Direction: Downlink	experiment ID: FSD12	figures: Figure 94- Figure 98	objectives: Data link data transmission in flight

1. A slightly increased number of lost messages can be observed during some stages of the flight (see Figure 96).

   9:40 :This increase of the losses was during the landing in Frankfurt Runway 25L. Since the NEAN ground station is directly located at Frankfurt airport this would not a-priori be expected. The following reasons may have caused this effect:

   (i) loss of GPS signal reception thus causing failure in the slot synchronisation of the NEAN transponder. A loss of the GPS signal was indeed also observed by the flight crew in their GPS instruments;

   (ii) an obstacle between the NEAN ground station and the aircraft antenna (either a building or even the fuselage of the trials aircraft itself);

   (iii) multipath effects, since the aircraft was flying close to the ground the reflected signals arrived with significant relative signal strength and therefore could have interfered with the direct signal.

   9:58 :The aircraft was on the ground on a taxiway. It may be that some obstacles were again between the aircraft and the ground station or still the GPS reception was interfered.

   10:29 - 10:51 :The aircraft was on a path which was more than 35 nm away from the ground station. The reduced signal/noise ratio and consequently a higher likelihood for lost messages was the result. It should be noted that still messages could be exchanged up to the farest distance of 60 nm however the number of retries increased and many messages were actually lost.

   11:09 - 11:29: The aircraft was in decent and approach to the Hahn airport. The distance to the Frankfurt ground station was above 35 nm.

   The NEAN datalink works fine as long as the distance to the ground station is below 35 nm. Above this distance the probability of lost messages increases. However it is still possible to use the NEAN data link up to the distance of 60 nm where the flight was also performed.

2. The transmission latency changes slightly during the flight but always stays below 1500 ms (Figure 97).

   No more than two retries were used to transfer the data packets on the downlink.

   The increased transmission latency time around 09:45 was during taxiing in Frankfurt. The increased transmission latency around 10:32 was on a track north east of Frankfurt in a distance of about 50 nm. The last increase around 11:16 is related to the decent and landing in Hahn where the distance to the ground station in Frankfurt again was above 50 nm.

3. The loss rate and the transmission latencies are significantly lower on the downlink than on the uplink (compare Figure 90 and Figure 91 to Figure 96 and Figure 97).

   This means that there is no significant difference between the uplink laboratory

Observations	data link: NEAN		
Direction: Downlink	experiment ID: FSD12	figures: Figure 94- Figure 98	objectives: Data link data transmission in flight
and flight trials.			
4. Compared to the laboratory trials the transmission latency values are similar to those measured in the laboratory (see Figure 98 and the table below). There is no significant difference between the uplink laboratory and flight trials.			

Parameter		Results	
		Flight trial	**Laboratory**
Data Transmission Latency (all message lengths)	min	156 ms	200 ms
	average	402 ms	410 ms
	95 %	696 ms	670 ms
	max	1 311 ms	1 078 ms
Distance of low loss probability		~ 35 nm	-

Table 22: Data link data transmission in flight (NEAN downlink)

6.3.2 Mode S Flight Trials

6.3.2.1 Mode S Uplink Flight Trial

The Mode S uplink flight trial was performed on the 19th January 2000. The flight began at 09:35 UTC and ended 11:32 UTC. It included take off and climb, several course changes, and an approach and landing back in Hahn (HAN). The main track was flown twice (as indicated by the two different times indicated in the flight track. The related flight track is shown in Figure 99 and Figure 100.

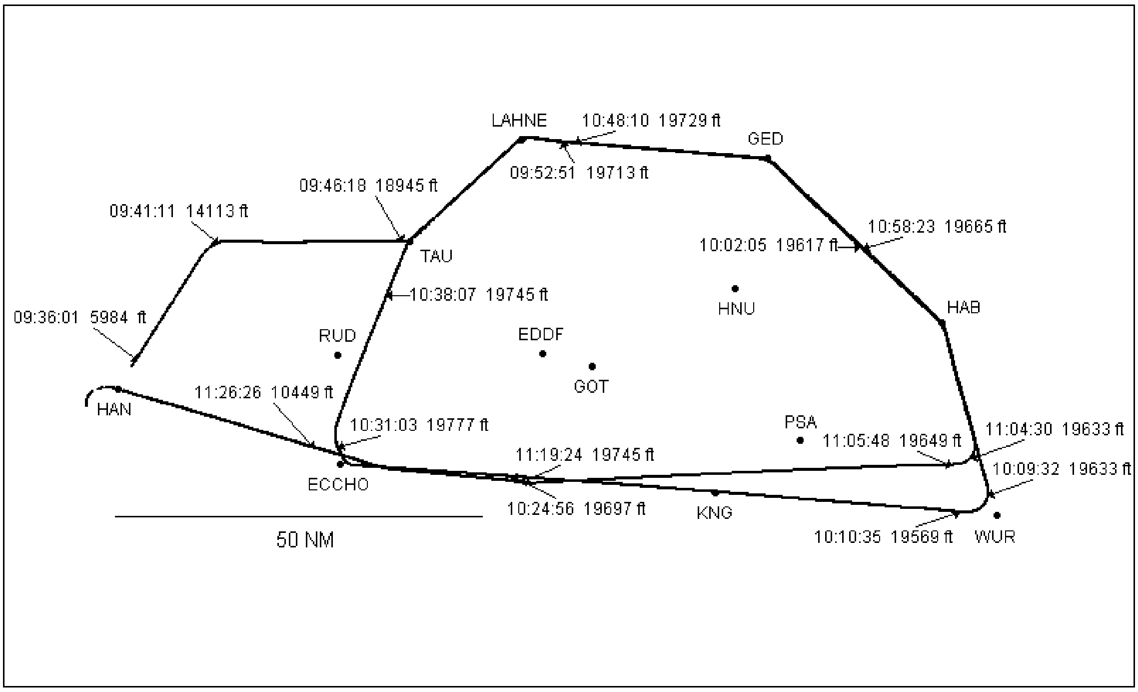

Figure 99: Mode S uplink Trial Flight Track

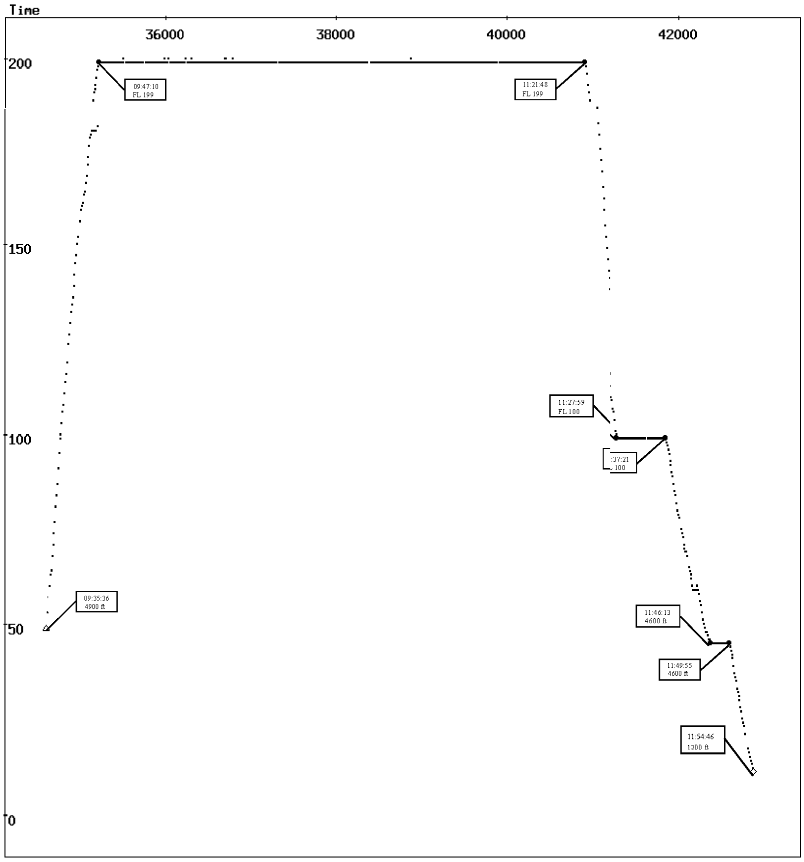

Figure 100: Mode S uplink Trial Flight Track (altitude)

The test results of the Mode S downlink trial flight are shown in the diagrams below.

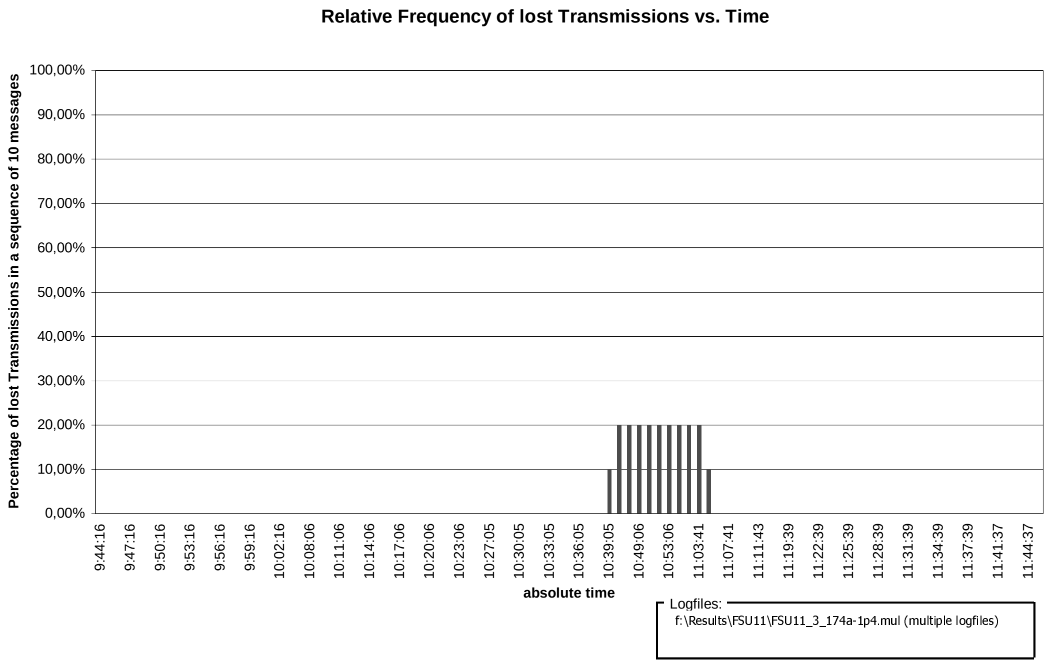

Figure 101: Percentage of lost Messages versus absolute Time (Mode S uplink Flight Trial)

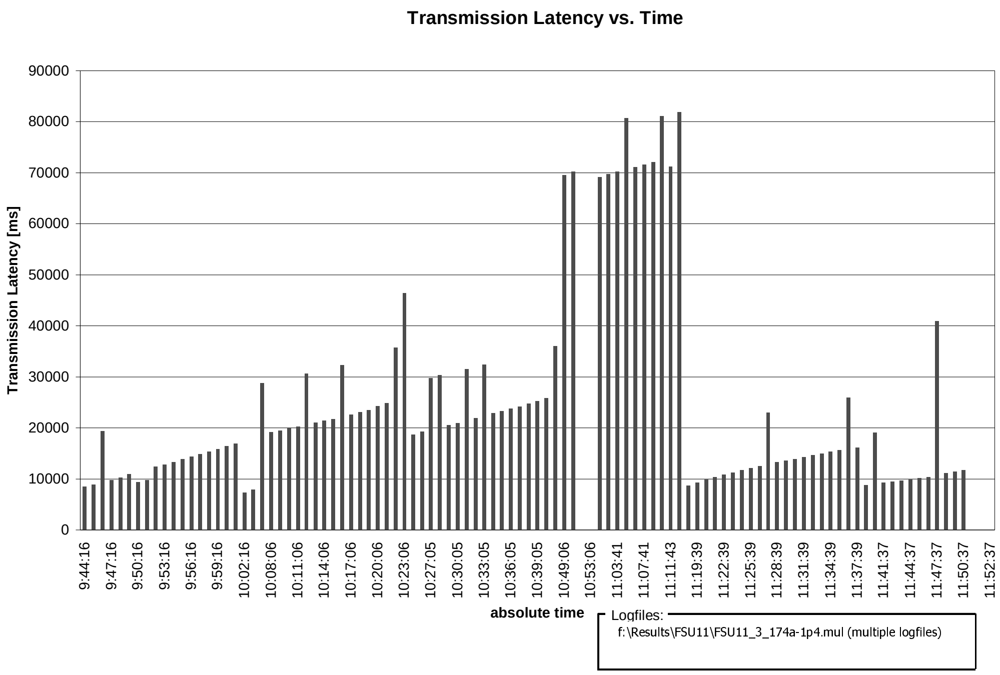

Figure 102: Data Transmission Latency versus absolute Time (Mode S uplink Flight Trial)

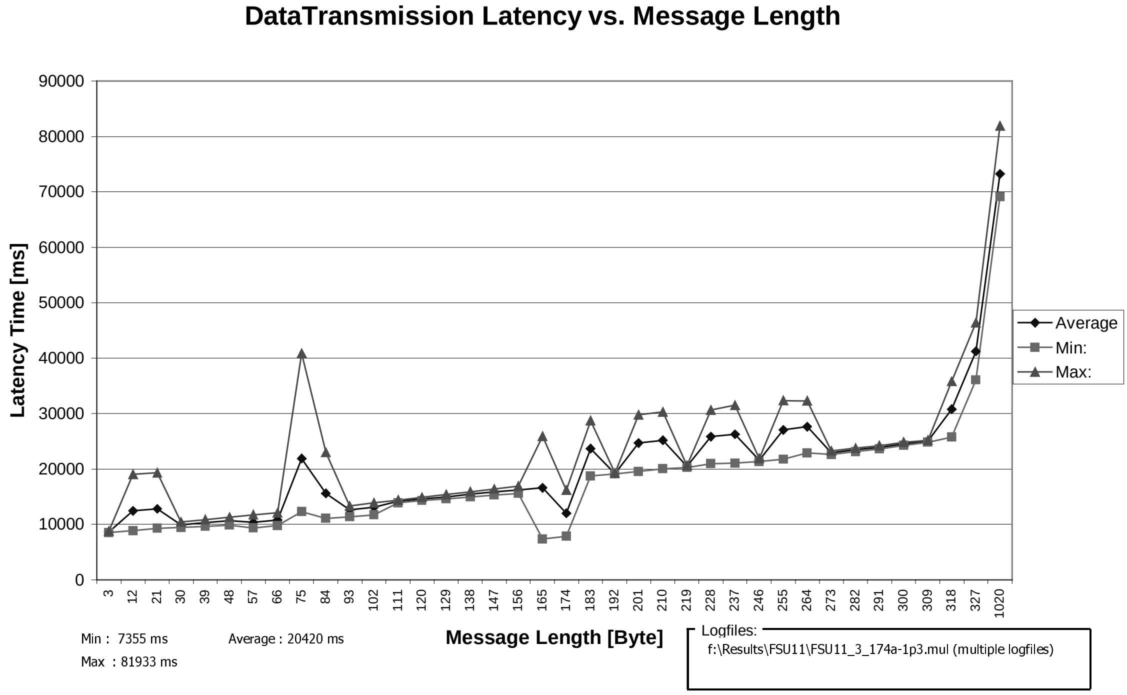

Figure 103: Data Transmission Latency versus message Length (Mode S uplink Flight Trial)

Observations	data link: Mode S		
direction: uplink	experiment ID: FSU11	figures: Figure 99 - Figure 103	objectives: Data link data transmission in flight

1. Only during a short time interval around 10:52 UTC two downlink messages of 1020 bytes were lost. (Please note that the averaging of the loss probability causes a spreading of the loss event) (see Figure 101).

   The reason for the loss was a Clear_Request which was issued by the Mode S data link system while still two messages of 1020 bytes were waiting in internal queues to be transmitted. The reason of the Clear_Request was not evident but such effects were also observed in the laboratory trials and are attributed to the experimental nature of the equipment rather than to actual system properties.

   In an operational implementation losses of this type are not expected.

2. The transmission latency changes with the time (Figure 102).

   This has two reasons:

   (i) The first reason for the increase is an interference between the radar antenna revolution time (i.e. 10 s) and the message sending intervals used by the ground DLTE (i.e. 60 s). As the message sending interval is a multiple of the antenna revolution time the same constellation should theoretically result each time a message is sent. Consequently the same transmission latency time should be observed each time a message is transferred. In fact the radar rotates slightly slower than 10 s so that a short period of time is added each time until the radar actually points to the target so that the transmission latency is increased from message to message.

   (ii) The second reason for the increase of the transmission latency is the increasing length of the data packets which require more and more transmission time. This especially is obvious for the 1020 bytes packets which have been sent between 10:53 and 11:13 UTC.

   The increase of the transmission latency with the time is an artefact caused by the strong control of the message transmission times. In an operational implementation the messages would be generated at random intervals, so that the fluctuation of one radar revolution time would also be observed but the mean value would be half the radar revolution time.

3. Sometimes the transmission latency shows peaks which are about 10 seconds larger than their neighbours (Figure 102).

   These increases are caused by lost uplink packets so that the packet is sent again after one antenna revolution. Consequently the transmission latency is increased by one antenna revolution duration. This was at least observed in the experimental Radar which obviously schedules the retransmissions offline during an antenna revolution for the next beam dwell. An operational radar might be able to immediately schedule retransmissions directly during the same beam dwell, so that the extra time of a retransmission is no more than 10 ms.

4. Compared to the laboratory trials the transmission latency values are significantly smaller in the flight trials than in the laboratory trials (especially the maximum values) (see Figure 103 and the parameters entered in the table below).

Observations	data link: Mode S		
direction: uplink	experiment ID: FSU11	figures: Figure 99 - Figure 103	objectives: Data link data transmission in flight

There is obviously a technical problem in the ground trials infrastructure which prevents the time efficient transmission of the data packets in general. The nearly similar minimal values show that there is no significant difference in principle.

This difference suggests that the results observed in the laboratory trials are not representative of real flight parameters of the Mode S uplink so that the shorter transmission latencies measured in the flight trials actually represent more accurately the real life parameters of the Mode S uplink.

Parameter		**Results**	
		Flight trial	**Laboratory**
Data Transmission Latency (all message lengths)	min	7 355 ms	7 123 ms
	average	20 420 ms	28 717 ms
	95 %	72 101 ms	168 178 ms
	max	81 933 ms	415 134 ms

Table 23: Data link data transmission in flight (Mode S uplink)

6.3.2.2 Mode S Downlink Flight Trial

The Mode S downlink flight trial was performed on the 19th January 2000. The flight began at 14:20 UTC and ended 15:50 UTC. It included start and climb, several course changes and an approach and landing back in Hahn (HAN). In contrast to the uplink flight trial the main track was not flown twice. Instead shortly after it was begun the second time the track was terminated by a left turn and a decent towards Hahn was performed. The related flight track is shown in Figure 104 and Figure 105.

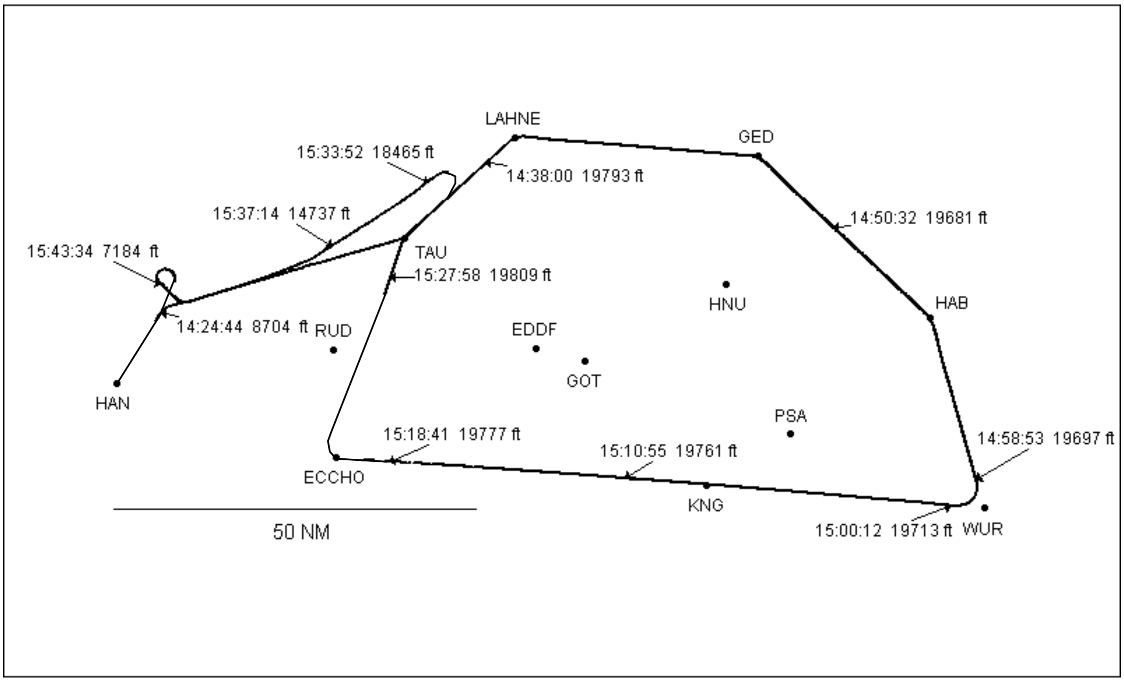

Figure 104: Mode S downlink Trial Flight Track

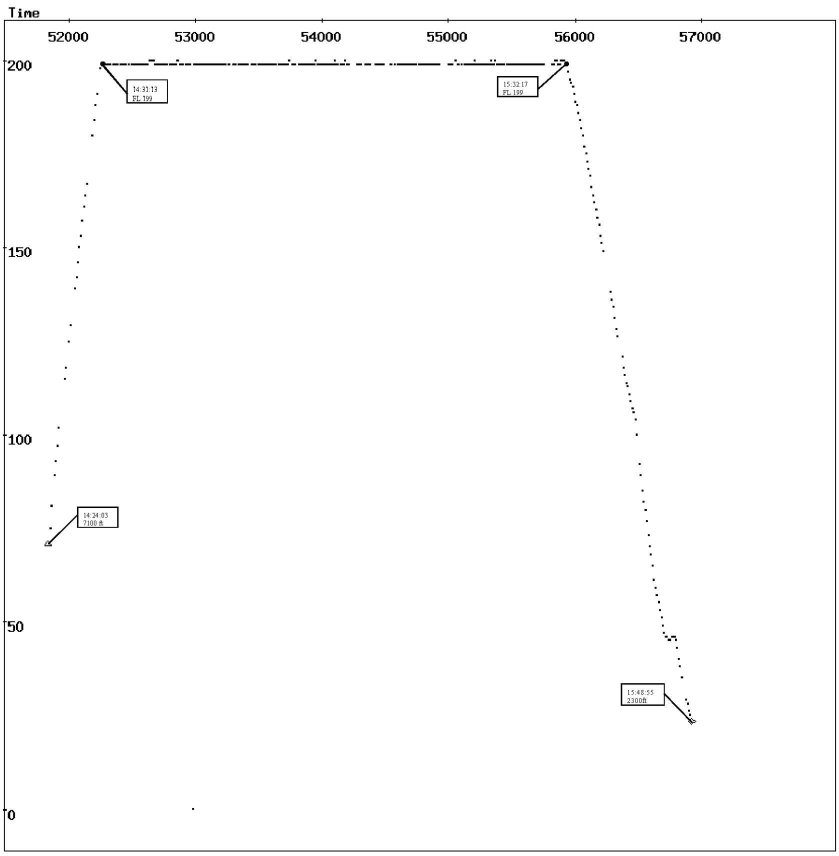

Figure 105: Mode S downlink Trial Flight Track (altitude)

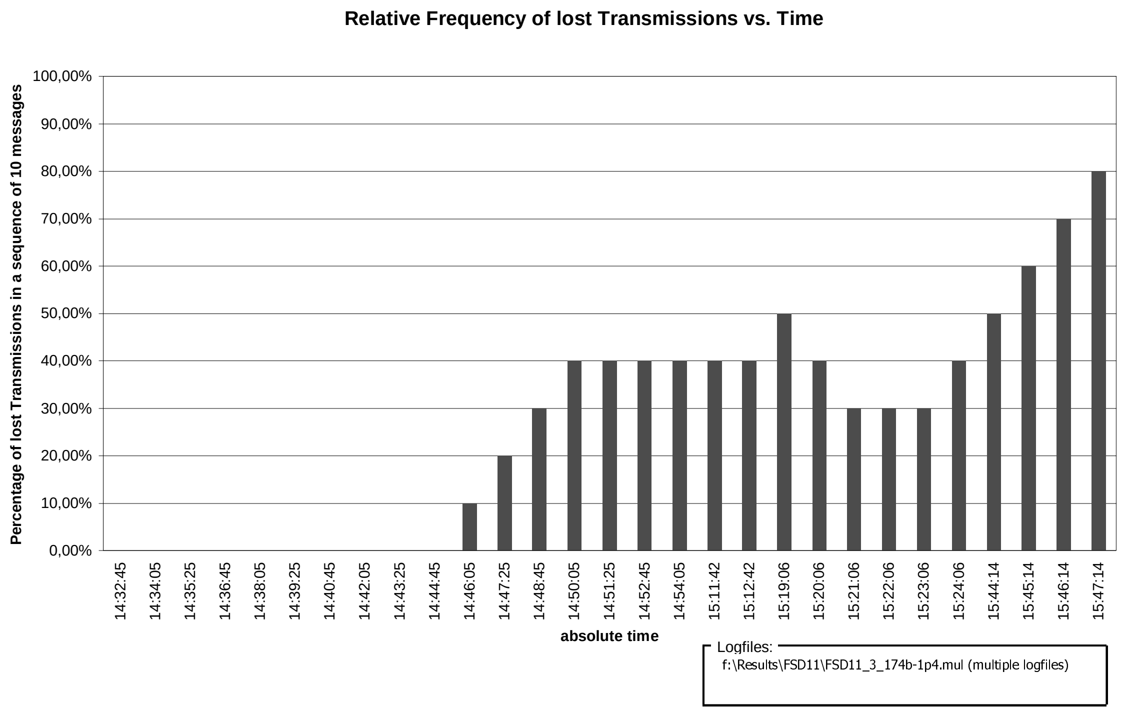

Figure 106: Percentage of lost Messages versus absolute Time (Mode S downlink Flight Trial)

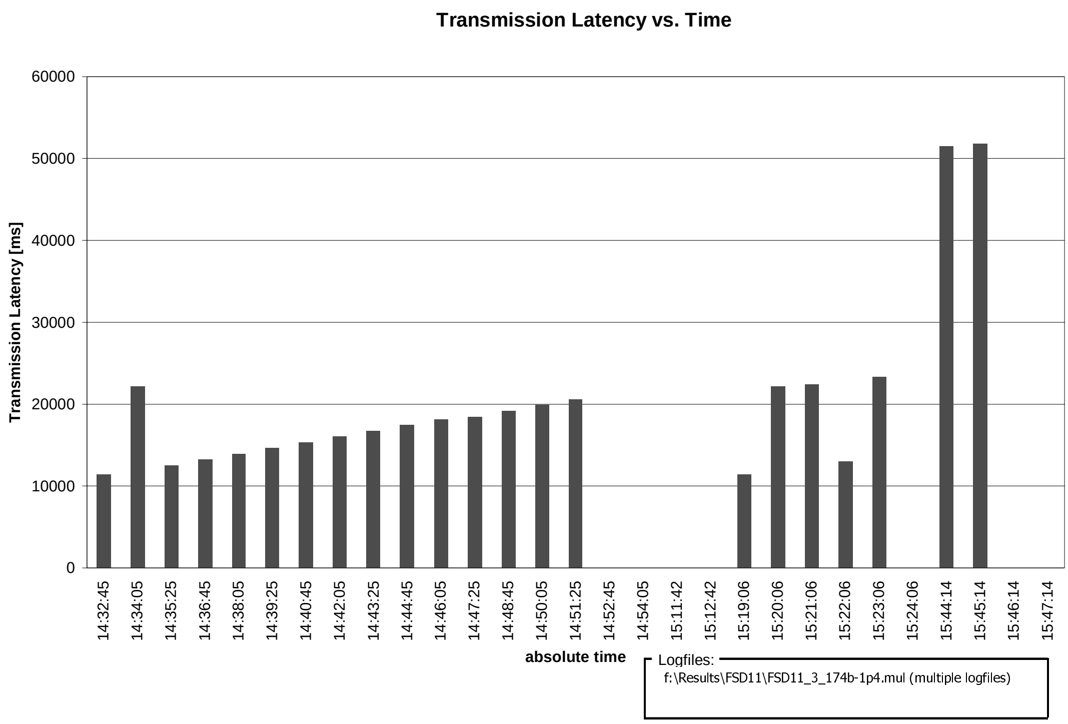

Figure 107: Data Transmission Latency versus absolute Time (Mode S downlink Flight Trial)

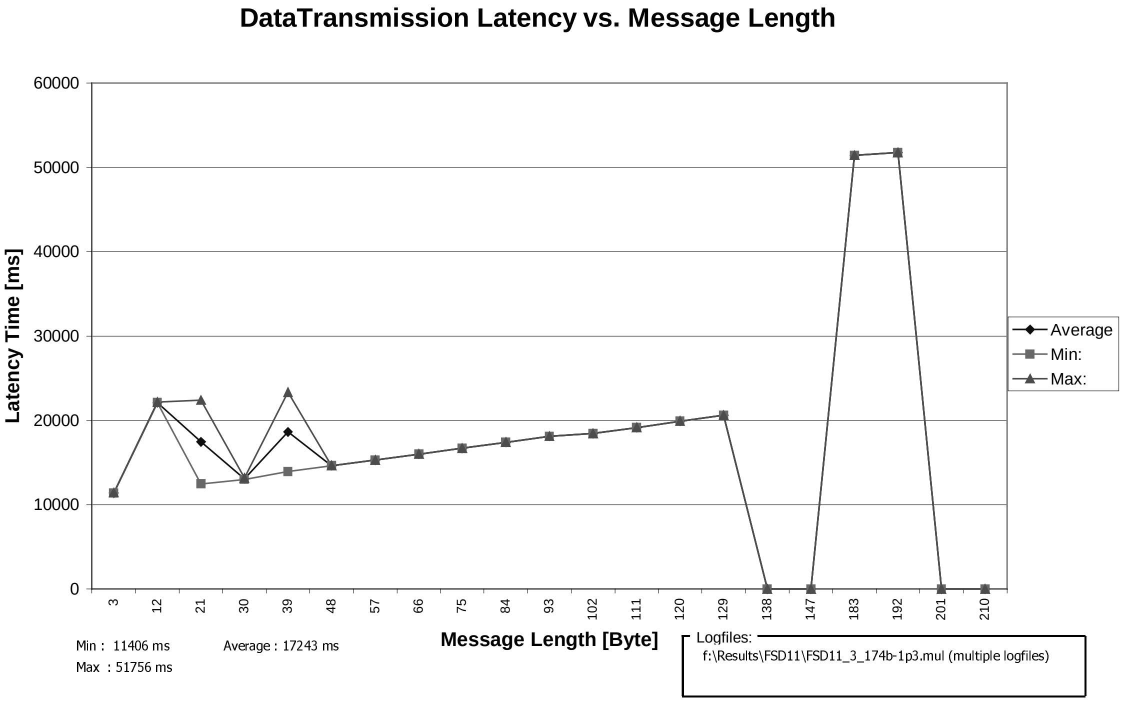

Figure 108: Data Transmission Latency versus Message Length (Mode S downlink Flight Trial)

Observations	data link: Mode S		
Direction: Downlink	experiment ID: FSD11	figures: Figure 104 - Figure 108	objectives: Data link data transmission in flight

1. Many losses were observed especially towards the end of the trial flight (see Figure 106).

   The reason for this problem was attributed to technical problems in the experimental setup. Repeatedly the ADLP in the aircraft reported a loss of surveillance from the radar (i.e. it did not receive surveillance interrogations any more) and terminated the connection. This could not be confirmed by the ground radar which reported a permanent surveillance tracking of the target.

   The problem was caused by implementation deficiencies either in the prototype airborne or experimental ground data link systems. Similar problems were already observed in the laboratory. As the effort to identify and solve such problems was not available within the budget of this study corrective actions could not be taken.

   As the problems were caused by implementation deficiencies of the experimental data link equipment such losses are not representative for the operational use of the data link. No losses of messages would have been observed in an operational system under the test conditions.

2. The transmission latency slightly changes with the time (see Figure 107)

   This has two reasons:

   a. The first reason for the increase is an interference between the rotation time of the radar and the sending moments of the data packets by the ground DLTE (also compare observation 2 of the Mode S uplink trials).

   b. The second reason for the increase of the transmission latency is the increasing length of the data packets.

3. Some message lengths are missing in the diagram at all (i.e. 138, 147 and all message lengths above 201 bytes) (see Figure 108).

   The reason for this is that the link broke down before all message lengths contained in a script file could be transferred.

   This again is an effect caused by the deficiencies of the experimental facilities. In an operational data link system such losses would not be observed.

Parameter		**Results**	
		Flight trial	**Laboratory**
Data Transmission Latency (all message lengths)	min	11 406 ms	--- ms
	average	17 243 ms	--- ms
	95 %	51 756 ms	--- ms
	max	51 756 ms	--- ms

Table 24: Data link data transmission in flight (Mode S downlink)

6.3.3 AMSS Flight Trials

6.3.3.1 AMSS uplink Flight Trial

The AMSS uplink flight trial was performed on the 21st January 2000. The flight began at 10:20 UTC and ended 12:42 UTC. It included take off and climb, several course changes, a circling between 11:05 UTC and 11:53 UTC and an approach and landing back in Hahn (HAN). The related flight track is shown in Figure 109 and Figure 110.

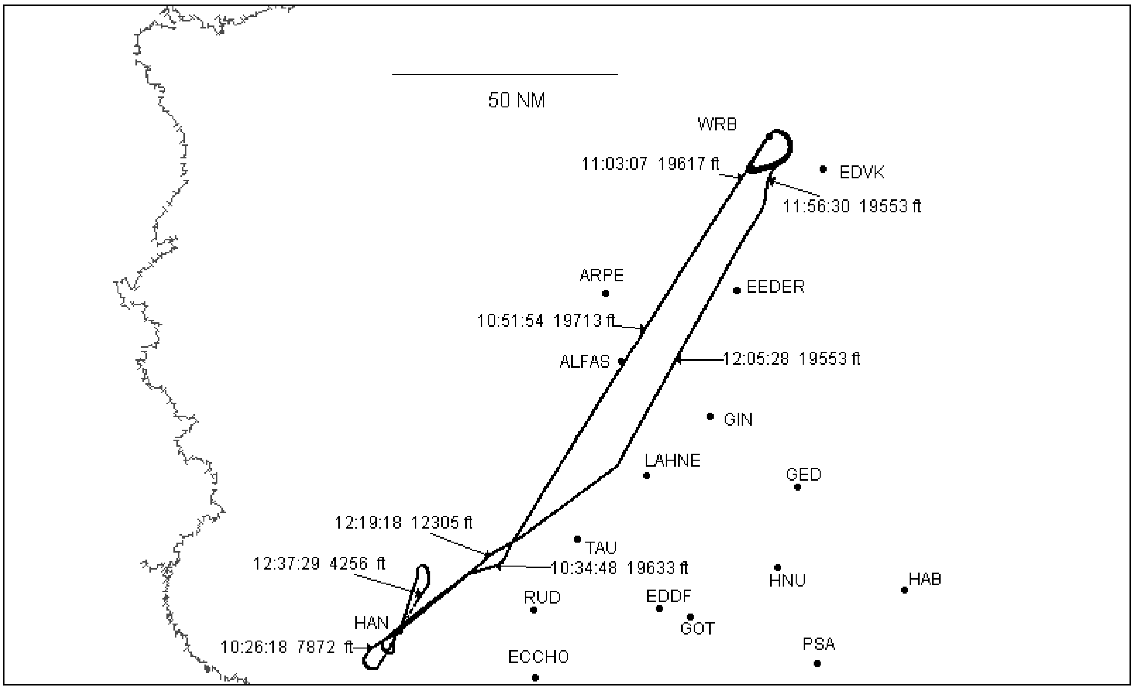

Figure 109: AMSS uplink Trial Flight Track

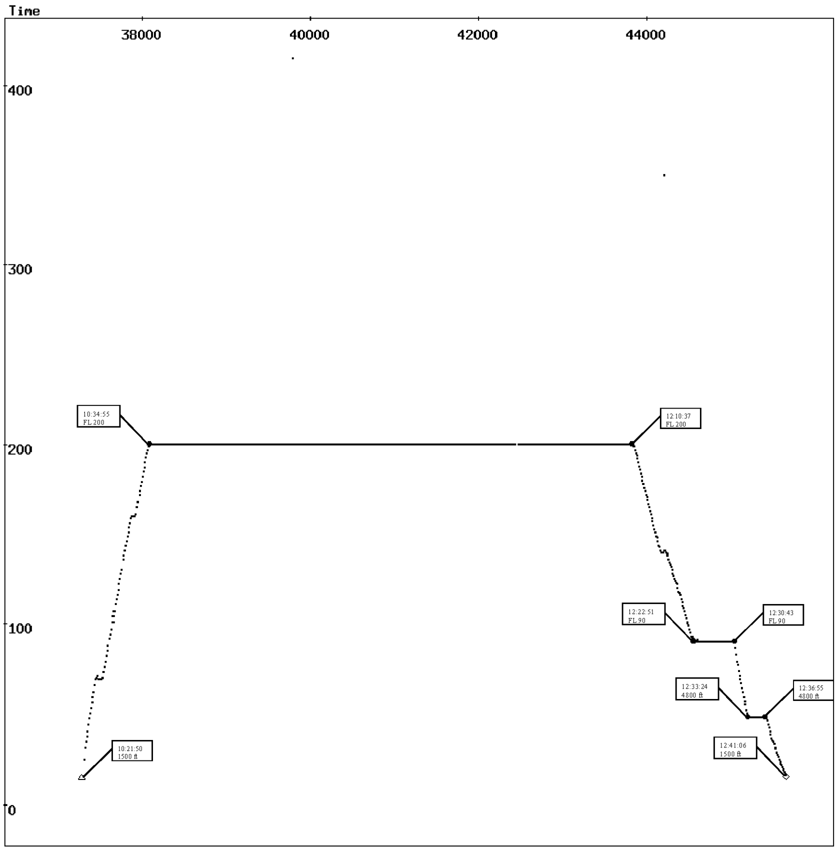

Figure 110: AMSS uplink Trial Flight Track (altitude)

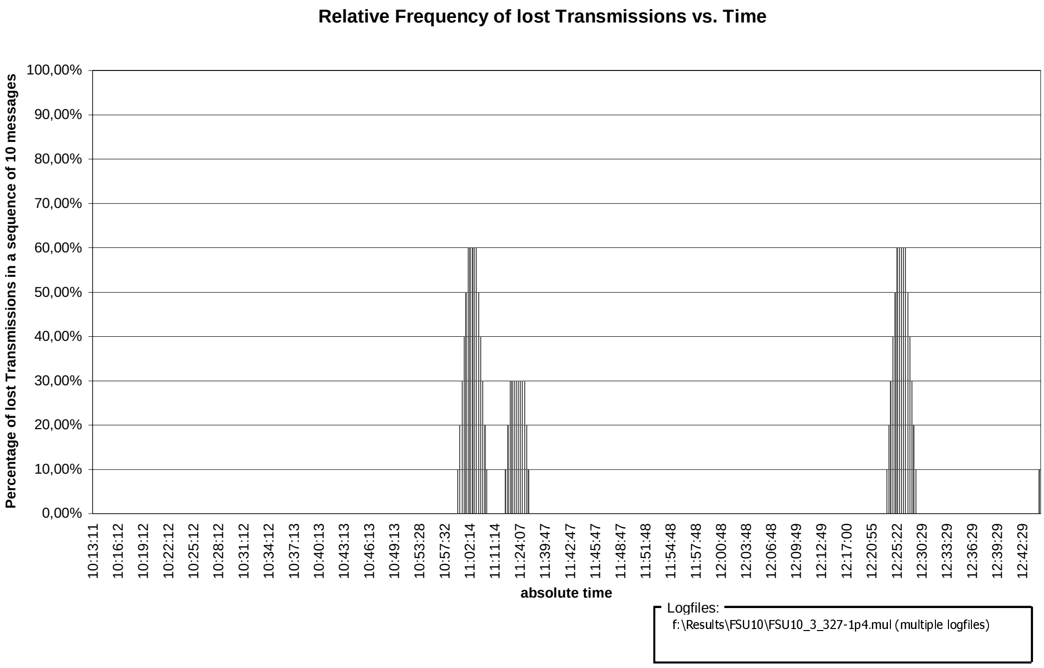

Figure 111: Percentage of lost Messages versus absolute Time (AMSS uplink Flight Trial)

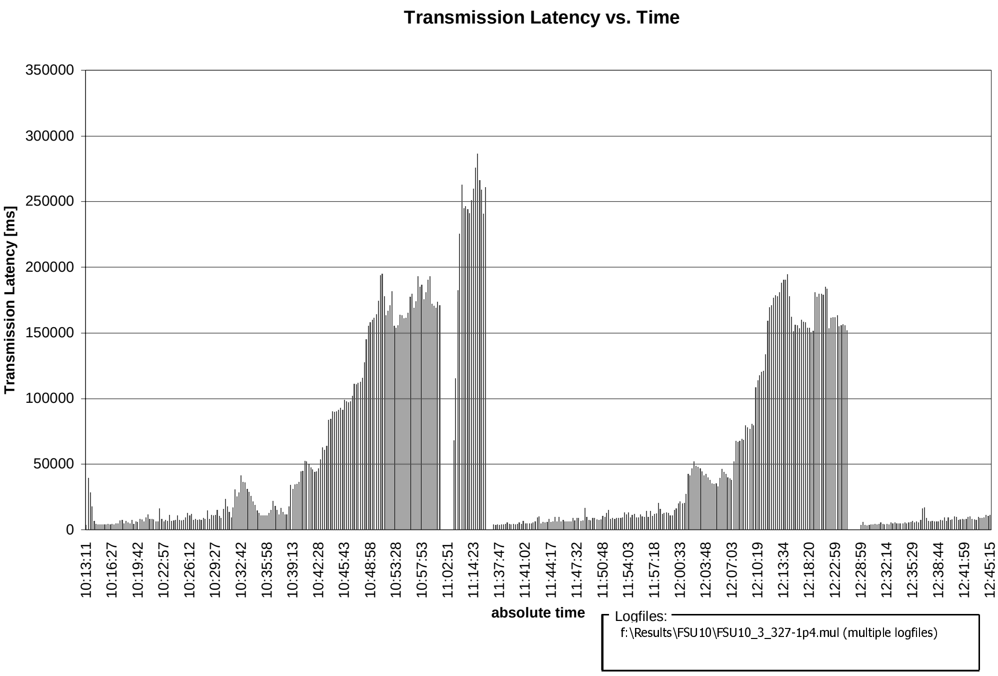

Figure 112: Data Transmission Latency versus absolute Time (AMSS uplink Flight Trial)

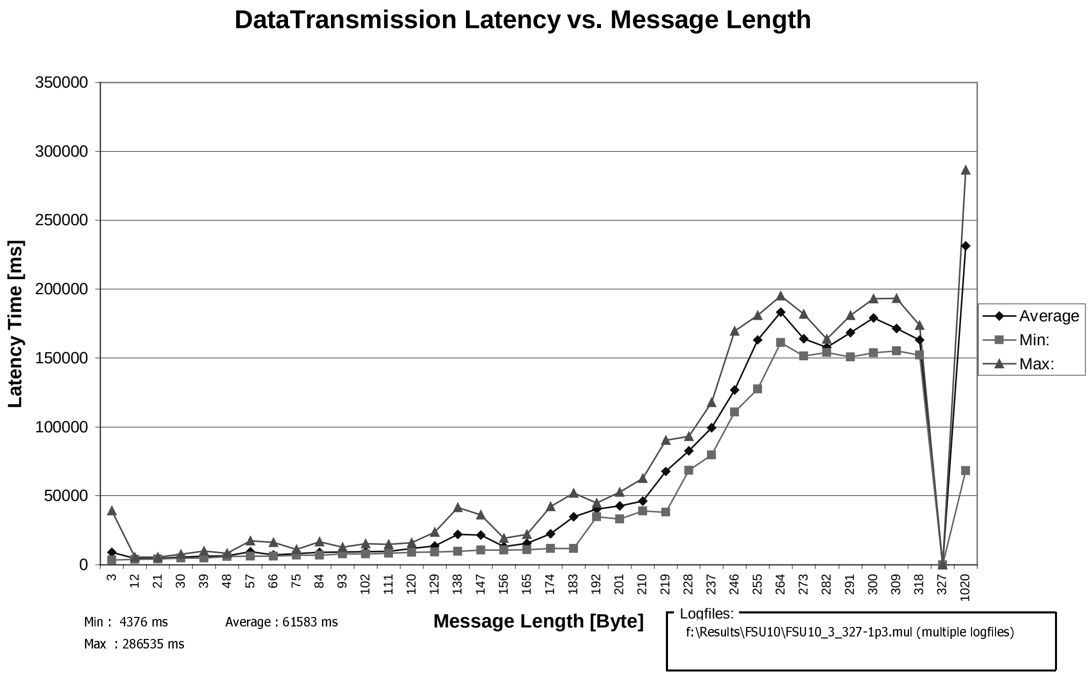

Figure 113: Data Transmission Latency versus Message Length (AMSS uplink Flight Trial)

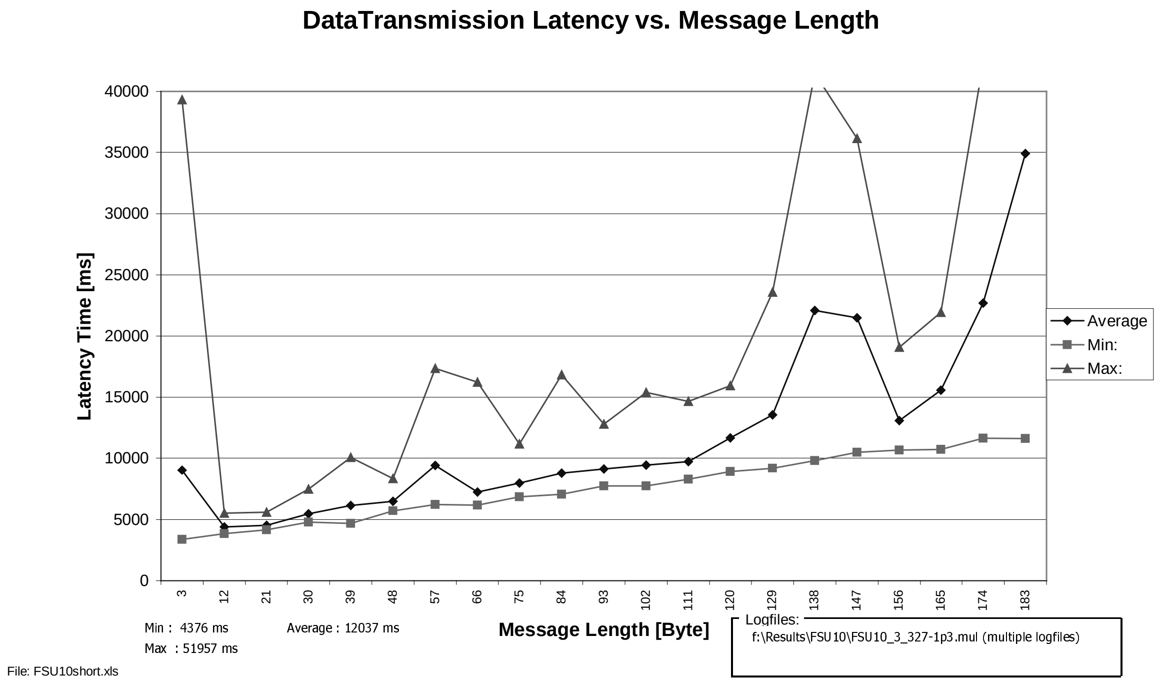

Figure 114: Data Transmission Latency versus Message Length for shorter Messages only (AMSS uplink Flight Trial)

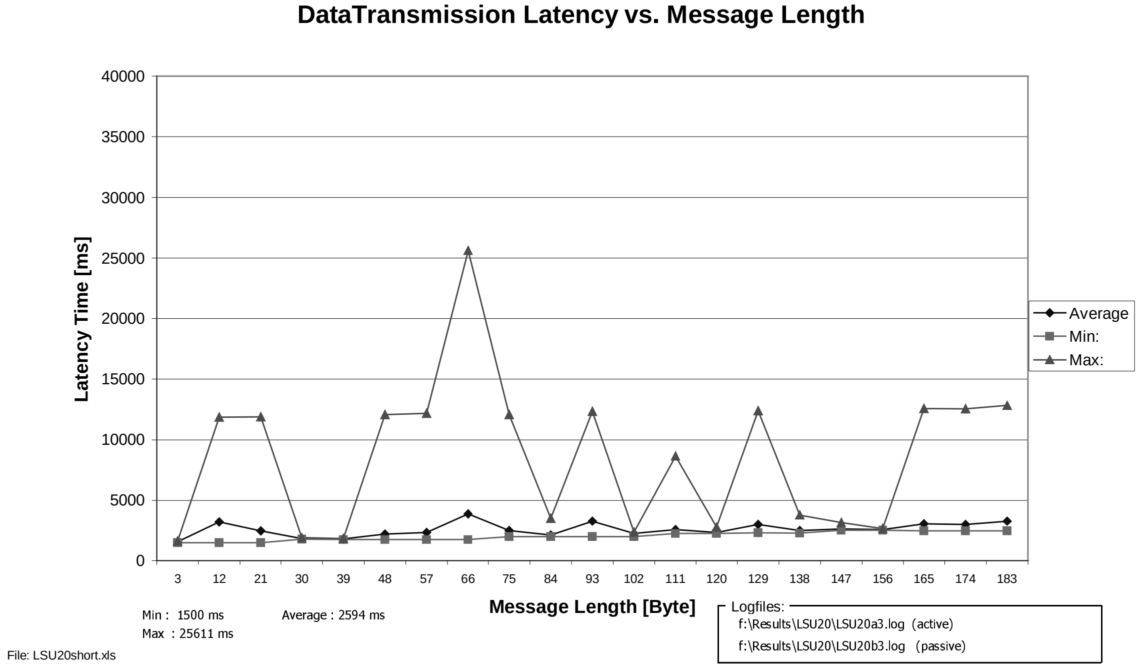

Figure 115: Data Transmission Latency versus Message Length for shorter Messages only (AMSS uplink Laboratory Trial)

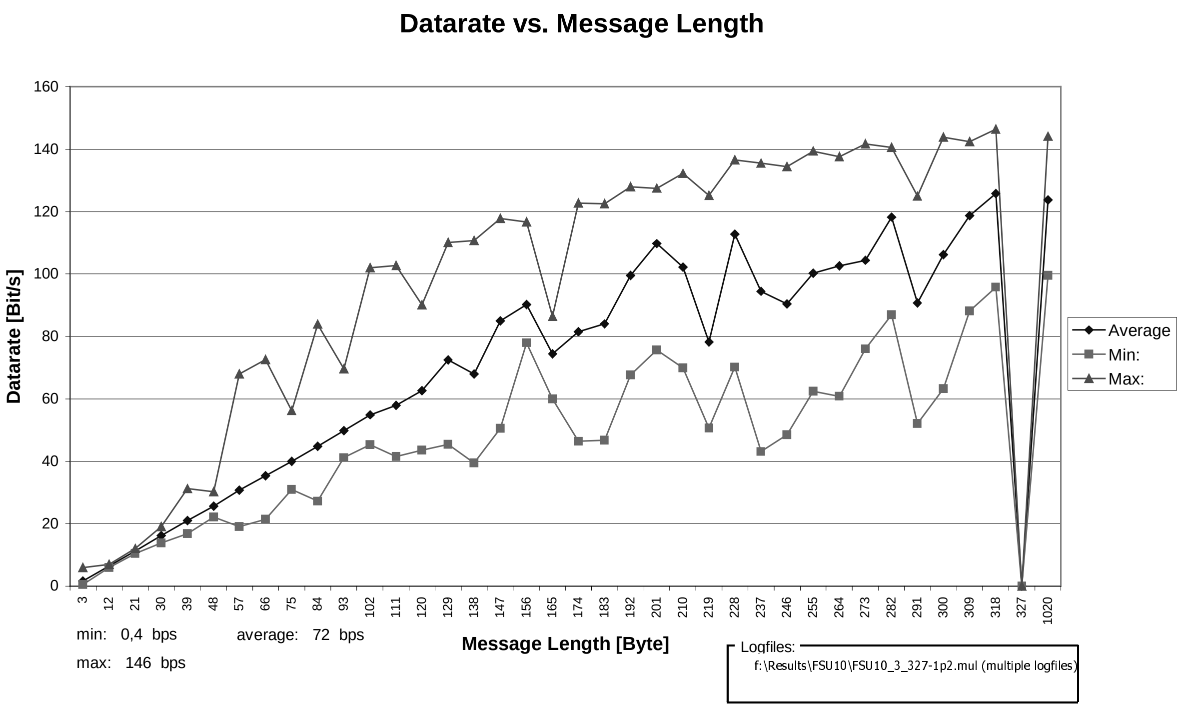

Figure 116: AMSS Data Link Data Rate versus Message Length (uplink Flight Trial)

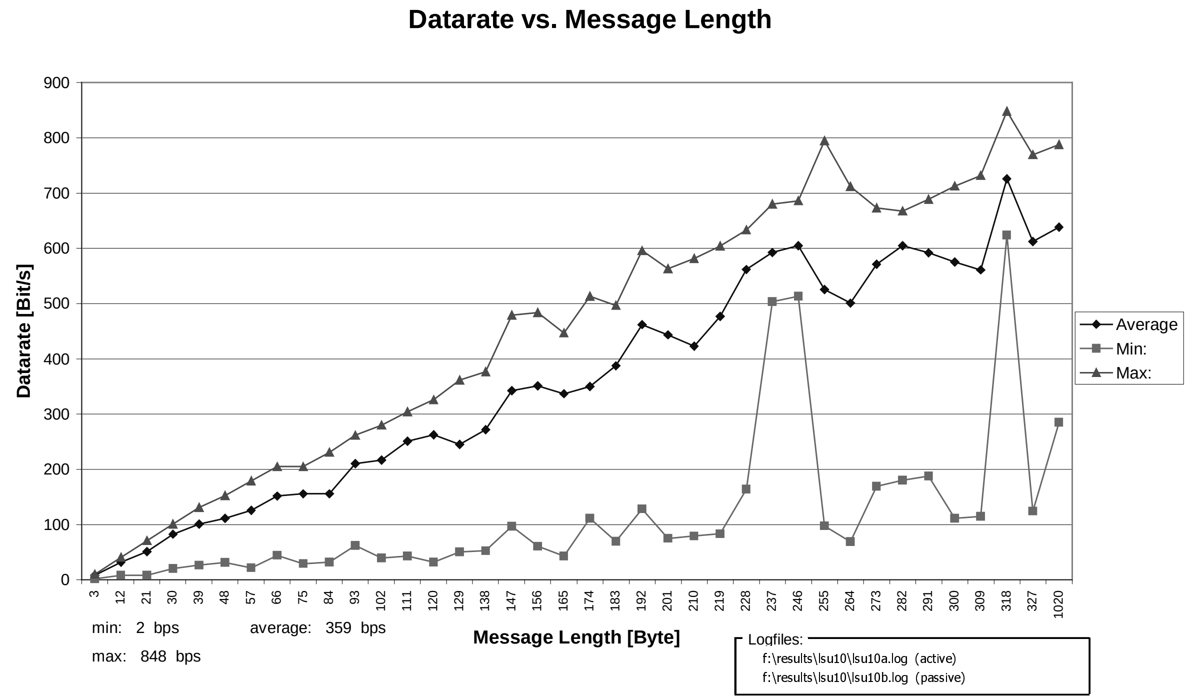

Figure 117: AMSS Data Link Data Rate versus Message Length (uplink Laboratory Trial)

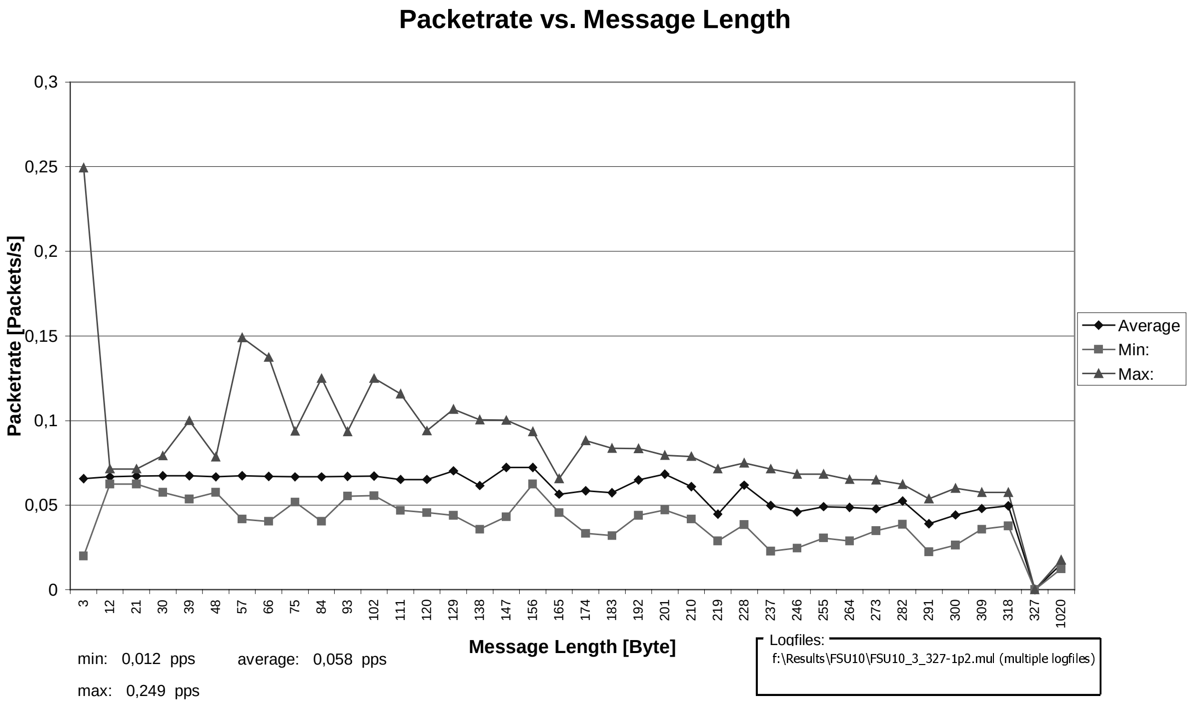

Figure 118: AMSS Packet Rate versus Message Length (uplink Flight Trial)

Observations	data link: AMSS		
direction: uplink	experiment ID: FSU10	figures: Figure 109 - Figure 117	objectives: Data link data transmission in flight

1. For some time losses of messages were observed (see Figure 111).

   The reason for this is as follows. The individual messages were sent from four script files which all ended by a Clear_Request so that the connection was cleared. The individual messages of the script file were sent at a constant interval which was sufficiently long to prevent the built up of queues in the laboratory trials setup where a high gain antenna was used. In the aircraft only a low gain antenna was available so that the interval between successive messages was not sufficiently long to cope with the lower bandwidth of the aircraft installation. Due to this queues built up in the AMSS system during the flight trials. This is also evident from Figure 112 where a significant increase of the transmission latency can be observed. Under these conditions messages were still stored in the queues when a script file ended and the connection was cleared.

   As the losses only occurred at the end of the logfiles only the incompatible setup of the test caused the effect. There were no losses observed otherwise. In an operational system no such losses would have to be expected.

2. The transmission latency increases with the time, for some time intervals even stronger (see Figure 112).

   This has two reasons:

   a. The first reason for the increase is the mentioned build-up of queues which causes extra delays if more data is sent than the AMSS data link can handle. The observed significant increase of the transmission latencies (e.g. between 10:36 UTC and 11:00 UTC) would not appear in real life as long as the message rate stays below a certain boundary so that the build-up of queues is avoided.

   b. The second reason for the increase of the transmission latency is the increasing length of the data packets which increases the transmission time. However the related effect can only clearly be seen at the short packets which did not cause a built-up of queues.

3. Message lengths of 327 bytes do not appear in Figure 113.

   This is caused by the fact that the 327 Bytes messages were the last in the script file and were still waiting in the queues of the AMSS when the Clear_Request was issued by the sending DLTE. The messages of 1020 bytes were again transferred, since they were located in a separate file but even there the last messages of the script file were lost for the same reason.

   The problem was only caused by the built up of queues and the clearing of the connection. The AMSS system is certainly capable of transferring 327 bytes messages under normal conditions as shown in the laboratory trials.

4. Compared to the laboratory trials the transmission latency values of the uplink flight trial are significantly higher (see Figure 113).

   The measurement results of the transmission latency are significantly affected by the built up of queues from a certain message length onwards. This is not the case

Observations	data link: AMSS		
direction: uplink	experiment ID: FSU10	figures: Figure 109 - Figure 117	objectives: Data link data transmission in flight

for message lengths below 183 bytes. For a comparison between the flight and the laboratory trial results only the transmission latencies for messages below 183 bytes may be used which are shown in the extra figures Figure 114 and Figure 115. It is clearly visible that the average transmission latency was significantly smaller in the laboratory trials (about 5 times). The reason for this difference is obviously the different aircraft installation where only a low gain antenna was available while a high gain antenna was used in the laboratory trials. The low gain antenna significantly reduces the bandwidth of the uplink channel and thereby causes a slower delivery of the messages.

To further analyse this aspect in terms of the data rate available in case of a low gain antenna, the receive data rates of the flight trial and the laboratory trial were compared (see Figure 116 and Figure 117). In order to derive data rate limits of a data link it is required to stimulate the channel with a higher data rate as it does support. As the flight trials were performed to determine the transmission latency this boundary condition was not in general fulfilled. The determination of the data rate therefore needs to be made with caution. It is however obvious that the data rate of the longest data packet (1020 bytes) is not higher than the data rate of the 318 bytes packet so that it can be concluded that the saturation of the channel is certainly reached from the 318 bytes packets onwards so that the data rate is actually limited by the data link and can be used as the value of the data rate. The saturation in case of a low gain antenna is reached at about 120 bit/s for the AMSS uplink flight trial. In contrast to this the throughput limitation is reached at 600 bit/s in the laboratory trials for the long packets. The significant influence of the low gain antenna on the uplink data rate is thereby clearly visible.

The data rates measured in the laboratory only apply to a high gain antenna installation. If a low gain antenna is used on the aircraft then the bandwidth of the AMSS uplink is significantly reduced.

Observations	data link: AMSS		
direction: uplink	experiment ID: FSU10	figures: Figure 109 - Figure 117	objectives: Data link data transmission in flight

Parameter		Results	
		Flight trial	**Laboratory**
Data Transmission Latency (3 to 201 Bytes message lengths)	min	4 376 ms	1 500 ms
	average	12 037 ms	2 594 ms
	max	51 957 ms	25 611 ms
Data rate	min	0,4 bit/s	2 bit/s
	average	72 bit/s	359 bit/s
	max	120 bit/s	848 bit/s
Packet rate	min	0,01 pps	0,03 pps
	average	0,06 pps	0,27 pps
	max	0,25 pps	0,43 pps
Test Conditions			

Table 25: Data link data transmission in flight (AMSS uplink)

6.3.3.2 AMSS downlink Flight Trial

The AMSS downlink flight trial was performed on the 12th January 2000. The flight began at 09:20 UTC and ended 12:10 UTC. It included start and climb, level flight, a holding, several course changes and an approach and landing back in Hahn (HAN). The related flight track is shown in Figure 119 and Figure 120.

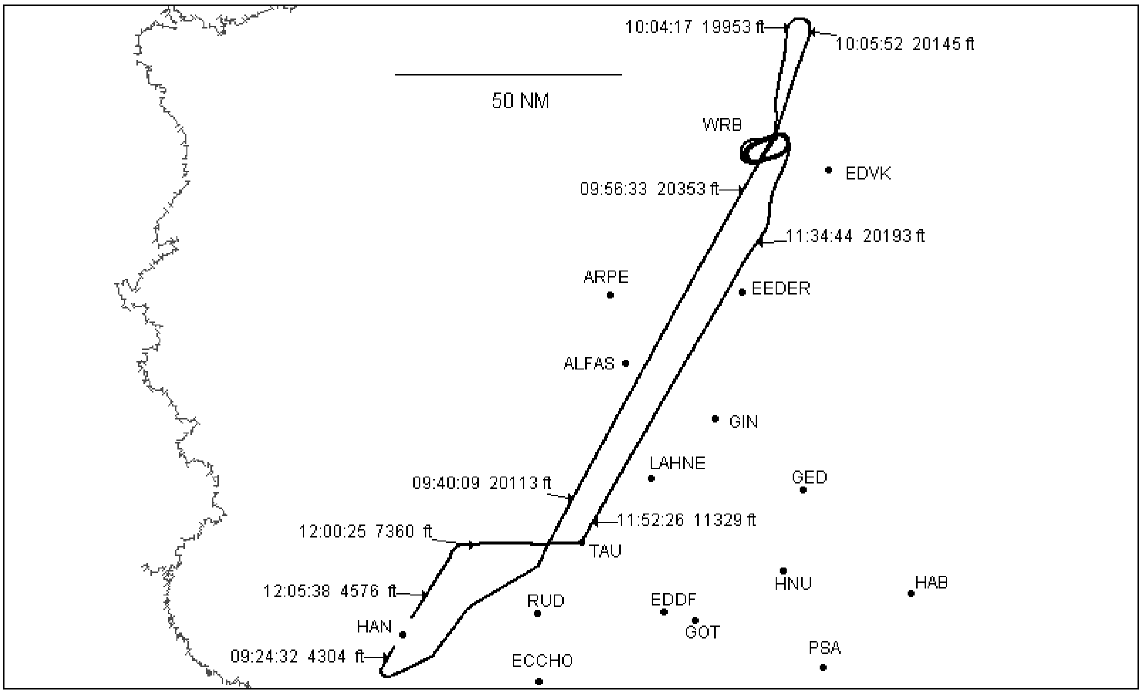

Figure 119: AMSS downlink Trial Flight Track

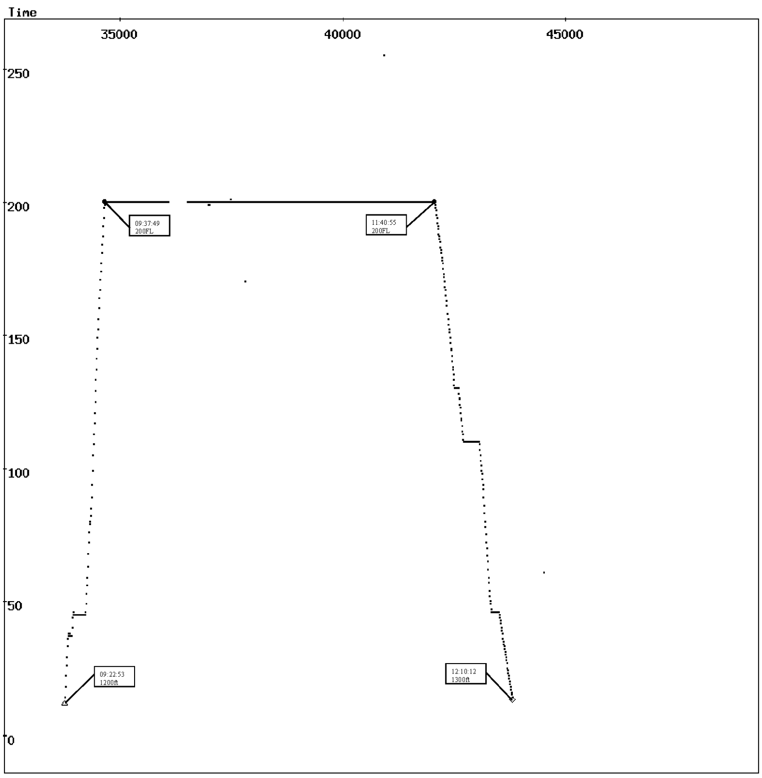

Figure 120: AMSS downlink Trial Flight Track (altitude)

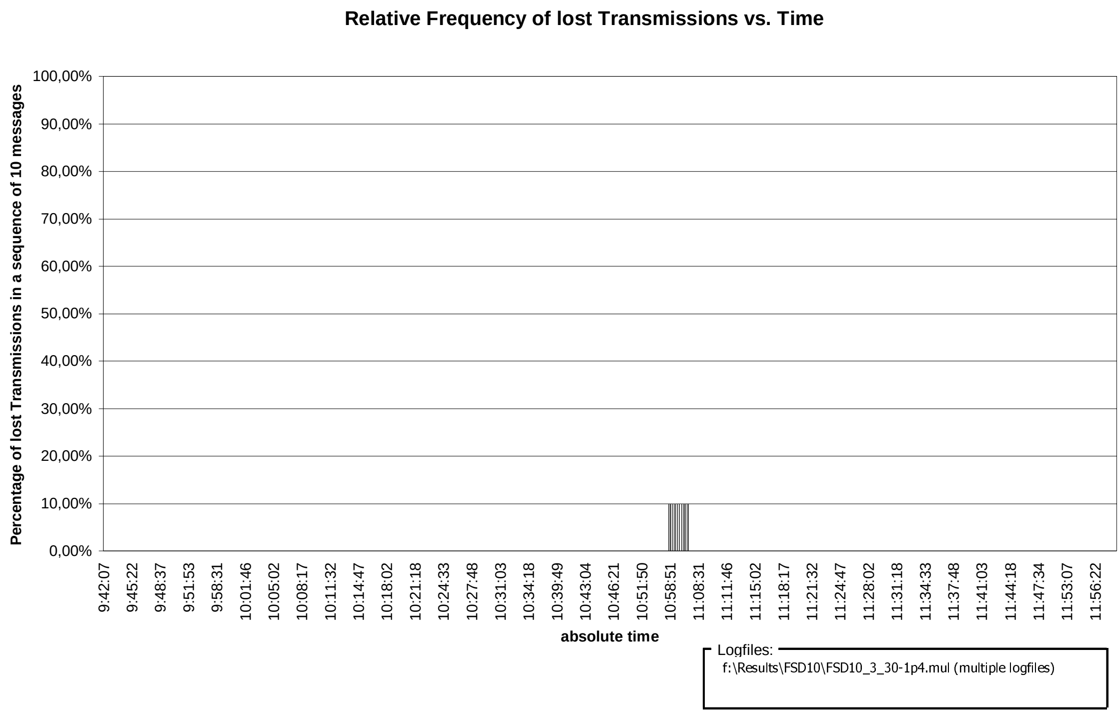

Figure 121: Percentage of lost Messages versus absolute Time (AMSS downlink Flight Trial)

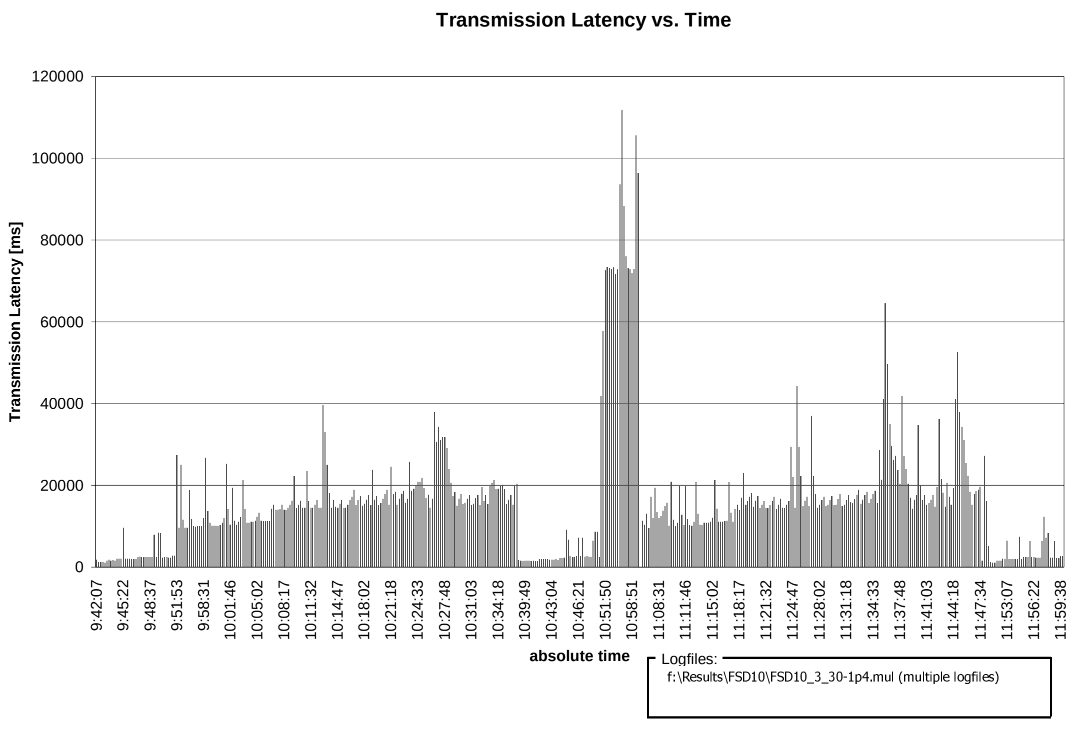

Figure 122: Data Transmission Latency versus absolute Time (AMSS downlink Flight Trial)

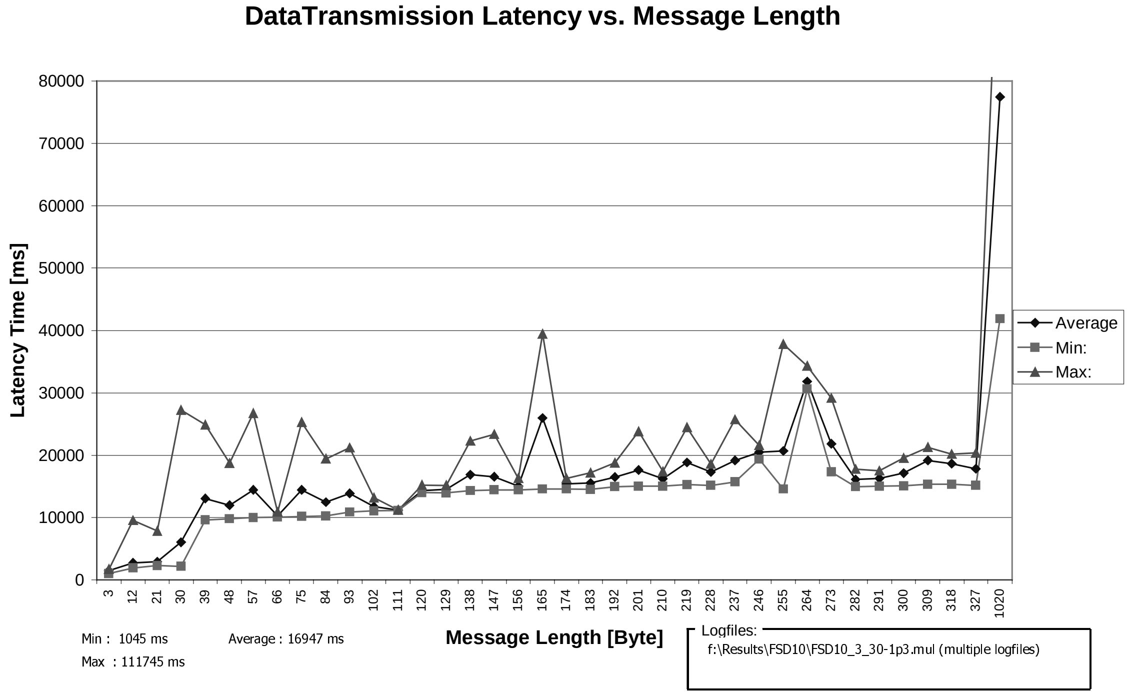

Figure 123: Data Transmission Latency versus Message Length (AMSS downlink Flight Trial)

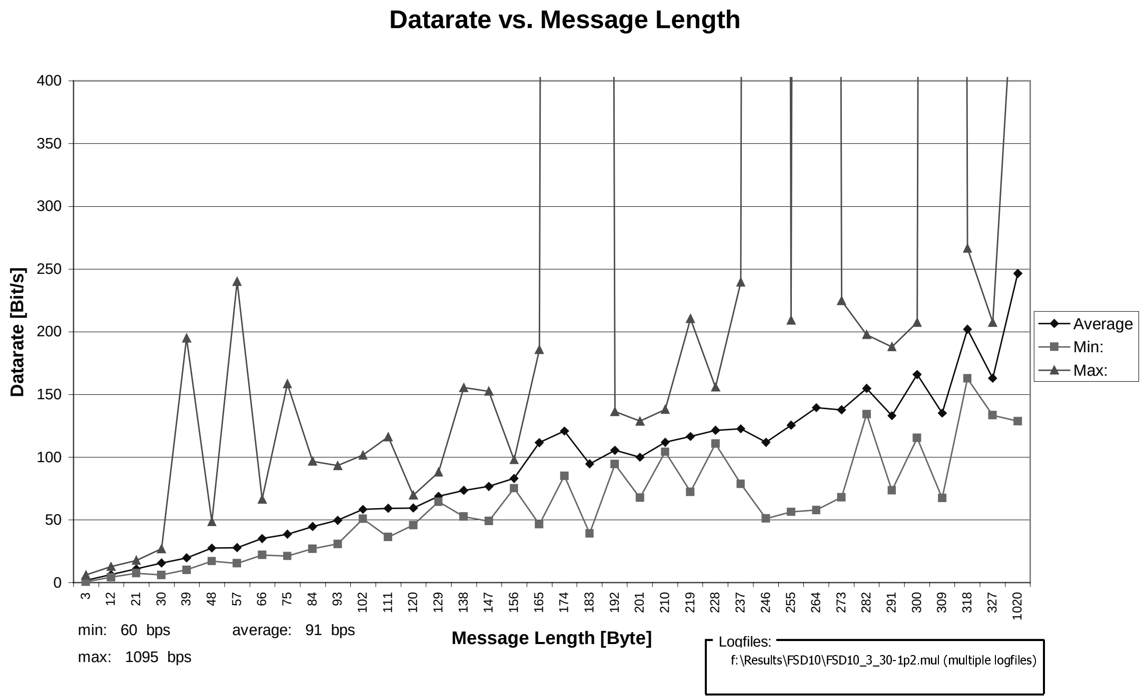

Figure 124: AMSS Data Link Data Rate versus Message Length (downlink Flight Trial)

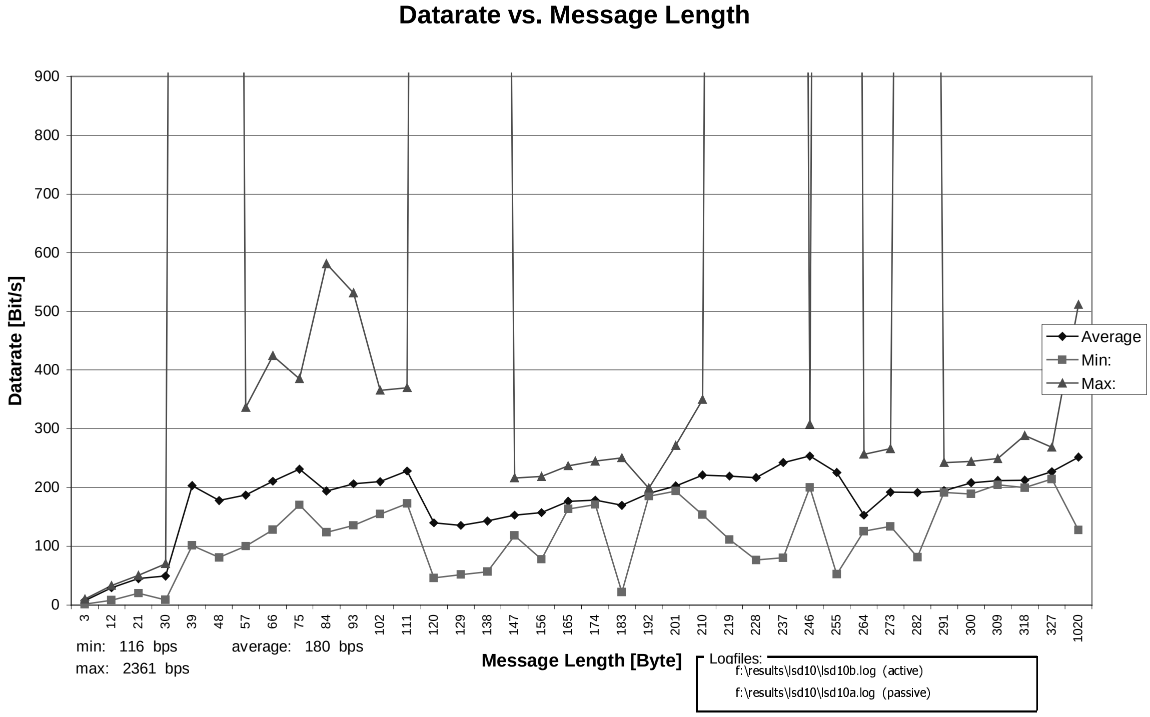

Figure 125: AMSS Data Link Data Rate versus Message Length (downlink Laboratory Trial)

Observations	data link: AMSS		
direction: downlink	experiment ID: FSD10	figures: Figure 119 - Figure 125	objectives: Data link data transmission in flight

1. A few losses of messages were observed around 11:00 UTC (see Figure 121).

   The reason for this loss is again the Clear_Request at the end of the 1020 bytes script file. In this case one single 1020 bytes message was not yet transferred when the clear request cleared the connection so that the last 1020 bytes message which was still stored in the AMSS data link medium was cleared prior of being delivered. A longer waiting time before the channel was cleared would have prevented this effect.

   As this loss only occurred at the end of a script file this was caused by the too early clearing of the connection and is not a property of the AMSS itself.

   No losses could be attributed to flight manoeuvres. The AMSS downlink channel would not show such losses in normal operation.

2. The transmission latency increases slightly with the time (see Figure 122).

   The reason for this is the increasing length of the data packets so that more and more time is required to transfer the data. This is especially visible for the messages sent around 10:54, where messages of 1020 bytes were transferred.

3. Figure 123 shows a significant increase between 30 and 39 bytes messages

   This increase is caused by the changeover from the R channel to the T channel for messages above 33 bytes. This is the same experience made as in the laboratory trials. No significant difference exists between the AMSS parameters between the use of a low or a high gain antenna on the downlink.

4. The characteristic transmission latency values obtained in the flight trial are in the same range as in the laboratory trials (see characteristic values as listed in the table below).

   In contrast to the uplink trials the limitation of the low gain antenna is much less significant on the downlink than on the uplink. This was due to fact that the SDU in the laboratory trials was set to 1200 bit/s for the downlink which artificially reduced the achievable data rate.

5. Figure 124 and Figure 125 show the receive data rate on the AMSS downlink compared to that measured in the laboratory trials. Both reach 250 bits/s on the downlink in case of long messages.

   The reason for that is the same as described under 4.

   Please note that the significant extremes of the data rate shown in Figure 124 and Figure 125 are caused by the fact that sometimes consecutive messages are temporarily stored in the system and then delivered to the destination almost one after each other so that the calculated short term data rate becomes indeed very high.

Parameter		**Results**	
		Flight trial	**Laboratory**
Data Transmission Latency	min	1 045 ms	1 067 ms

Observations	data link: AMSS			
direction: downlink	experiment ID: FSD10	figures: Figure 119 - Figure 125	objectives: Data link data transmission in flight	
(3 to 201 Bytes message lengths)	average	16 947 ms	14 557 ms	
	max	111 754 ms	142 144 ms	
Data rate	max	250 bit/s	250 bit/s	

Table 26: Data link data transmission in flight (AMSS downlink)

7 Comparison of the Trials Results

According to the objective of this study the data link media, AMSS, Mode S and NEAN were investigated in order to be able to compare their characteristic parameters. This section now shows the results of the data links in comparison to each other.

The following parameters are shown in comparison:

1. The Call Setup Latencies
2. The available User Data Rate per connection
3. The Data Transmission Latency and the percentage of lost Messages

7.1 Data Link Call Setup Latency Times

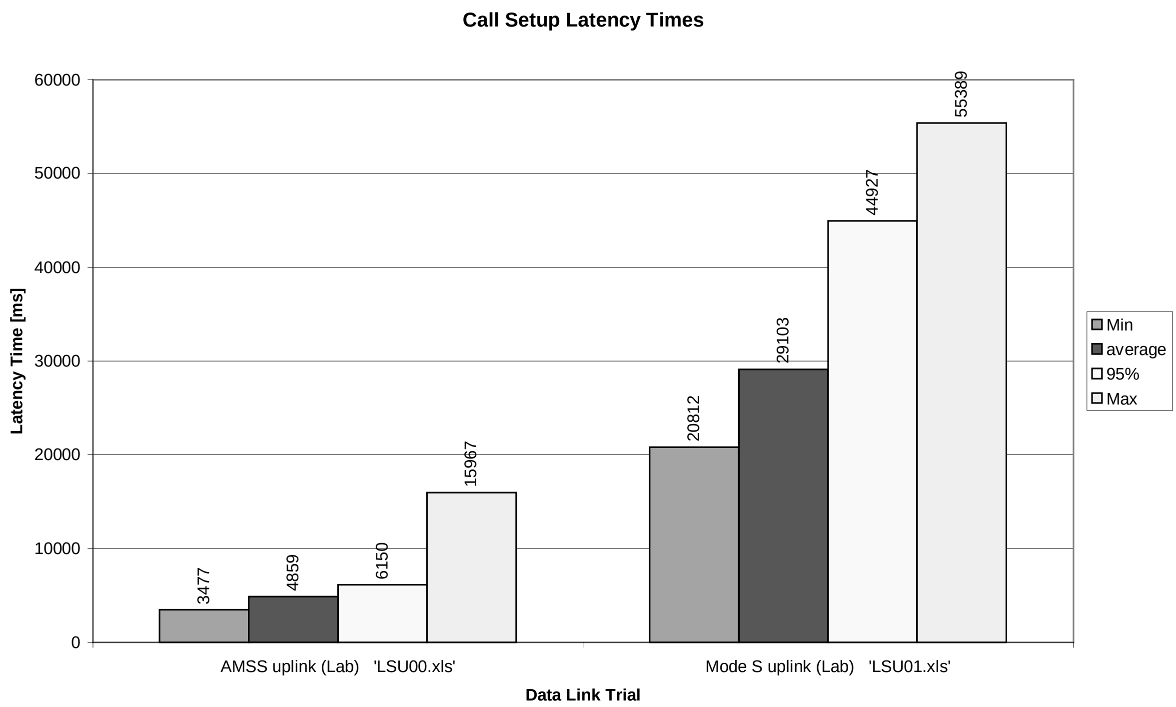

Figure 126: Measured Uplink X.25 Call Setup Latency Times of the AMSS and Mode S Data Link

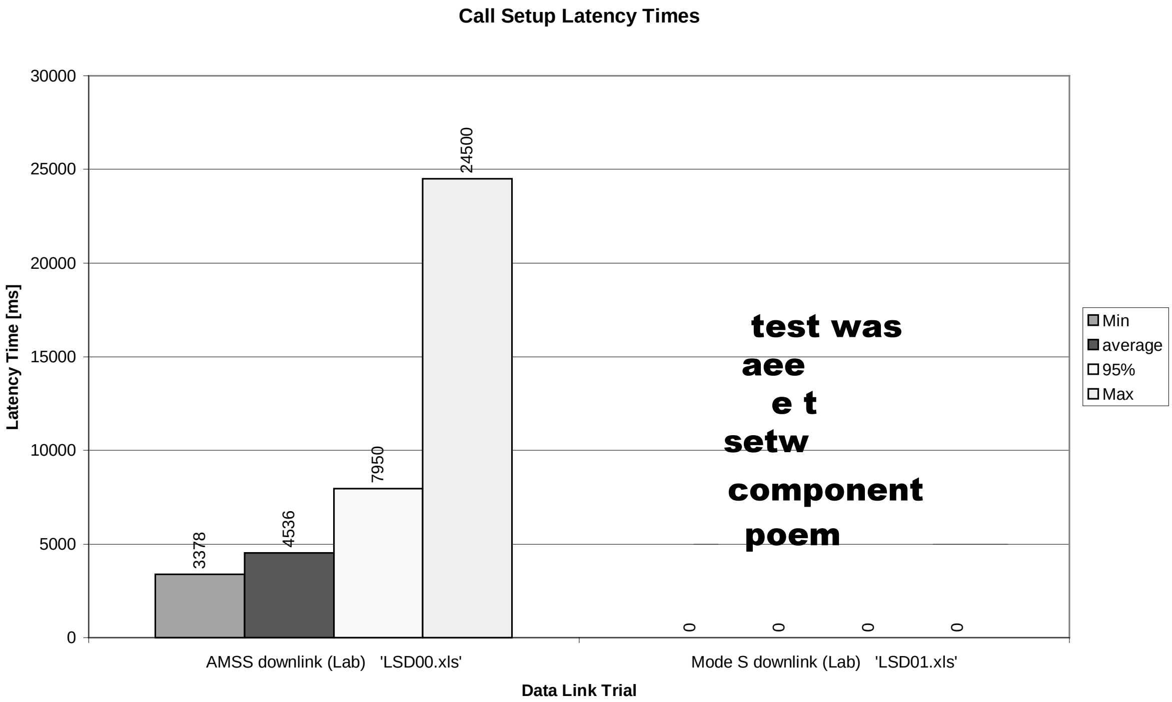

Figure 127: Downlink X.25 Call Setup Latency Times of the AMSS and Mode S Data Link

Observations	data link: AMSS, Mode S		
direction: uplink, downlink	experiment ID: LSU00, LSU01, LSD00, LSD01	figures: Figure 126; Figure 127	objectives: Comparison of Call Setup Latencies

1 Figure 126 shows that there is a significant difference between the X.25 Call Set-up latencies of the AMSS and the Mode S data link.

The larger access times of the Mode S channel are caused by the experimental equipment in combination with the rotating antenna. Since a Call Set-up requires to transfer messages on the up- and downlink and depending on message length and used formats, more than 1 scan (10 sec) is needed to complete the message transfer. This is clearly visible in the call setup latency times.

2 TBD

Parameter		**Results**	
		average	**95%**
AMSS Call Setup Latency uplink		4 859 ms	6 150 ms
Mode S Call Setup Latency uplink		29 103 ms	44 927 ms
AMSS Call Setup Latency downlink		4 536 ms	7 950 ms
Mode S Call Setup Latency downlink		---	---

Table 27: Comparison of Call Setup Latencies (AMSS, MODE S)

7.2 CPDLC Dialogue Establishment Latency Times

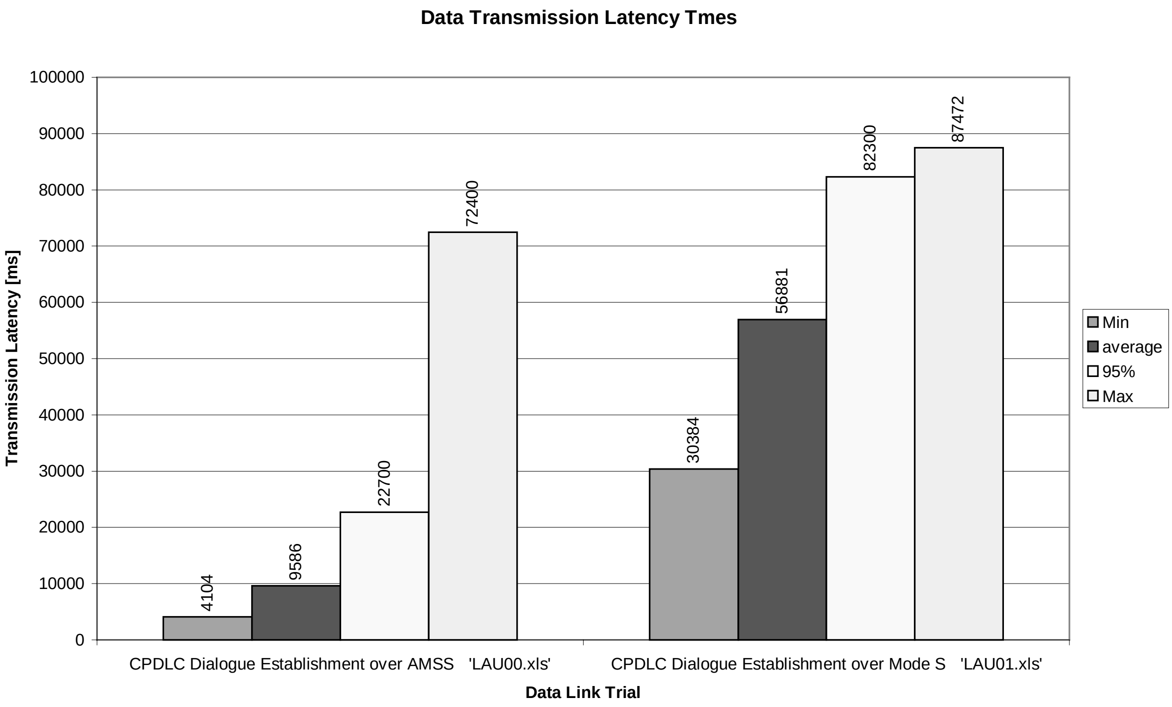

Figure 128: Uplink CPDLC Dialogue Establishment Latency Times

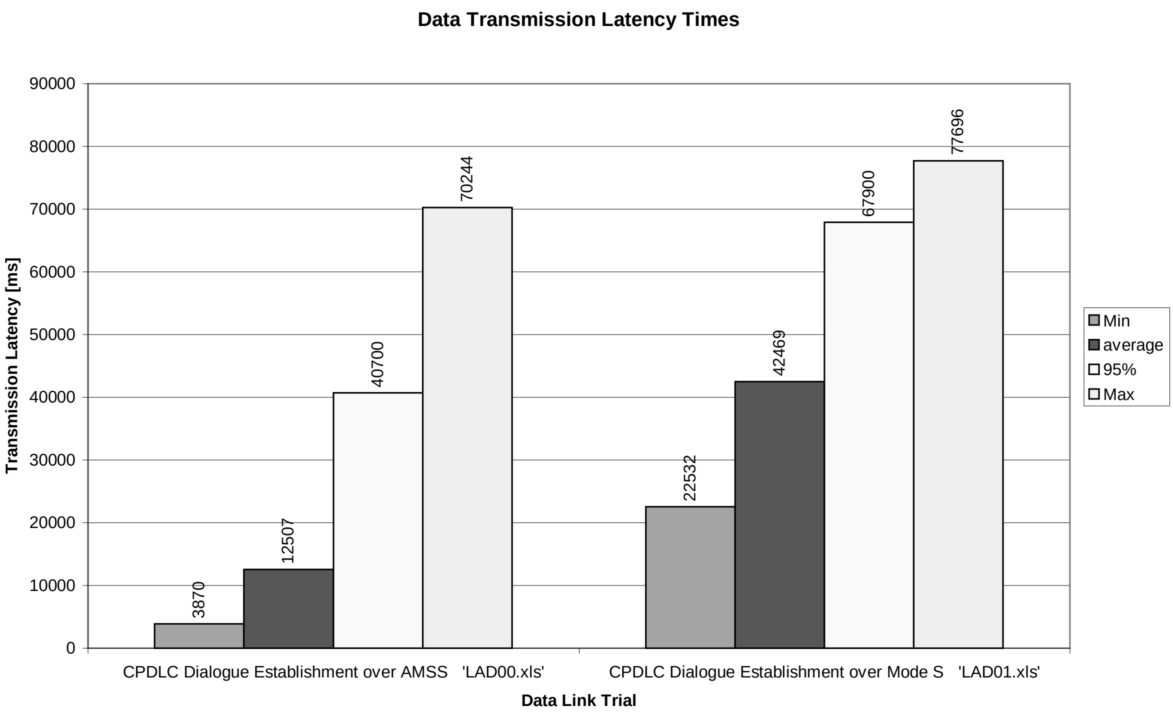

Figure 129: Downlink CPDLC Dialogue Establishment Latency Times

Observations	data link: AMSS, Mode S		
direction: uplink, downlink	experiment ID: LAU00, LAU01, LAD00, LAD01	figures: Figure 128, Figure 129	objectives: Comparison of the CPDLC Dialogue Establishment Latencies

1. Figure 128 and Figure 129 show a significant difference between the CPDLC dialogue establishment latencies of AMSS and Mode S.

   Again the experimental Mode S Radar plays a significant role and causes a poorer performance of the CPDLC Dialogue establishment over Mode S.
2. Compared to the minimum uplink Data transmission latencies (Figure 132 and Figure 133) the minimum CPDLC Dialogue Establishment latencies are about 3 times as big as the transmission latency for short data link messages.

   The reasons for that observation is that more than one single short message is required to establish a dialogue (i.e. one uplink and one downlink)

Parameter		**Results**	
		average	**95%**
CPDLC Uplink Dialogue establishment over AMSS		9 586 ms	22 700 ms
CPDLC Uplink Dialogue Establishment over Mode S		56 881 ms	82 300 ms
CPDLC Downlink Dialogue establishment over AMSS		12 507 ms	40 700 ms
CPDLC Downlink Dialogue Establishment over Mode S		42 469 ms	67 900 ms

Table 28: Comparison of the CPDLC Dialogue Establishment Latencies (AMSS, Mode S)

7.3 Data Link User Data Rates

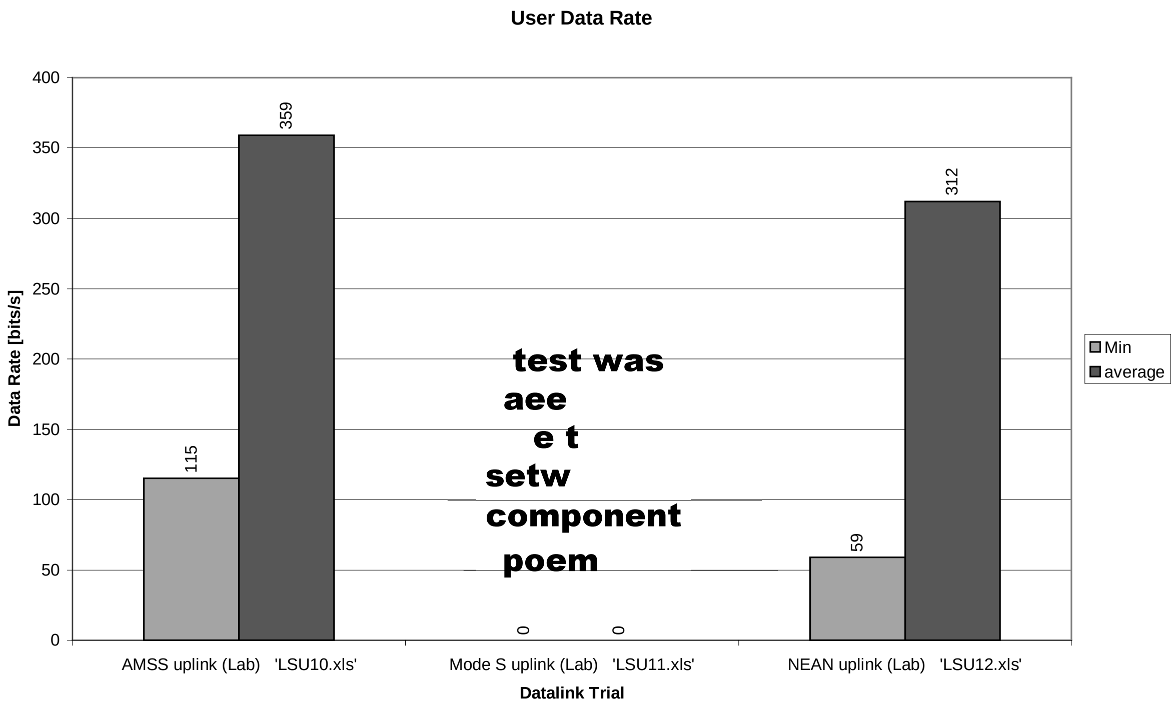

Figure 130: Achievable Uplink User Data Rates of the different Data Links

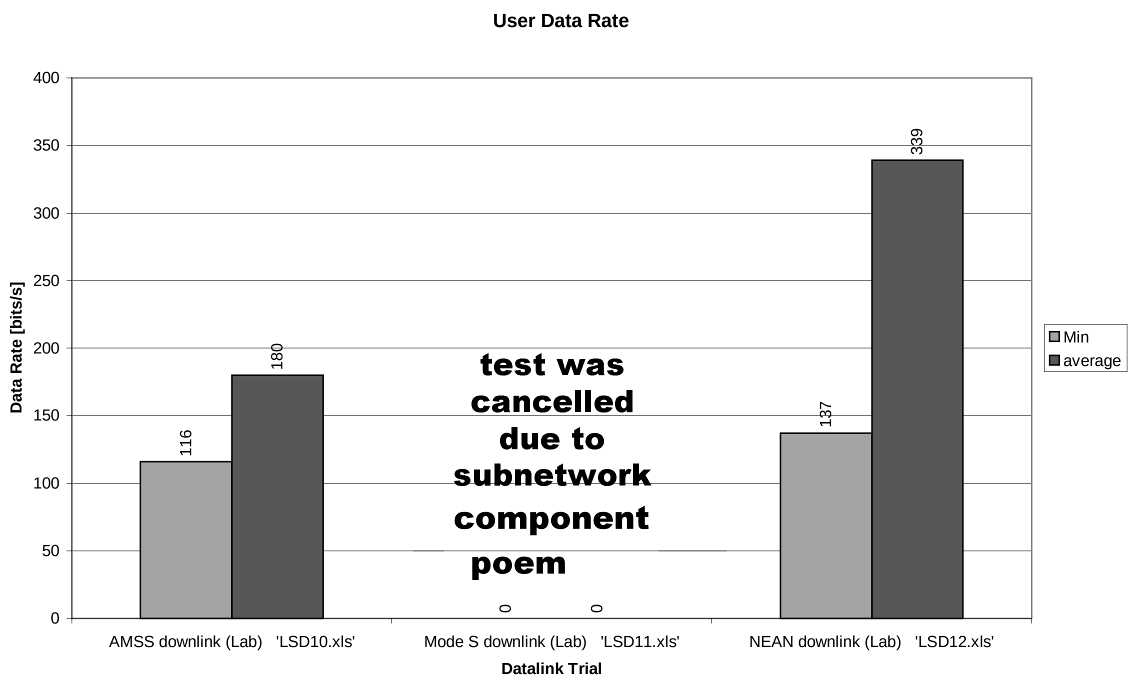

Figure 131: Achievable Downlink User Data Rates of the different Data Links

Observations	data link: NEAN, AMSS, Mode S		
direction: uplink, downlink	experiment ID: LSU10, LSU11, LSU12, LSD10, LSD11, LSD12	figures: Figure 130, Figure 131	objectives: Comparison of Data Link User Data Rates

1	Figure 130 shows only a small difference in the average user data rates for the AMSS and the NEAN data link whereas the AMSS datalink has a slight advantage over the NEAN data link. Not only is the AMSS uplink data rate higher than that one of the NEAN datalink, it is also much more reliable than the NEAN datalink and consequently provides even more capacity. However this is only true with the current performance of the NEAN uplink. In contrast to this the NEAN downlink has a better performance which also can be expected for the uplink in an operational system. Then both the AMSS and the NEAN data links offer similar capacity under the current traffic loads. However the NEAN data link was only used in an environment in which very few participants were present. A degradation of the measured performance must be anticipated in a fully populated environment.
2	Figure 131 shows a slightly better capacity of the NEAN downlink over the AMSS data link. This was due to fact that the AMSS SDU in the laboratory trials was set to 1200 bit/s for the downlink which artificially reduced the achievable data rate. Otherwise (if the SDU has been set to10500 bit/s for the downlink) a similar situation could be expected for the downlink as for the uplink.
3	An asymmetry was observed in the NEAN data link during the trials. It may be assumed that the NEAN data link offers the same higher capacity also on the uplink as operational equipment would be used in the future.

Parameter		**Results**	
		Min	**average**
AMSS uplink Data Rate		115 bits/s	359 bits/s
Mode S uplink data rate		----	----
NEAN uplink data rate		59 bits/s	312 bits/s
AMSS downlink Data Rate		116 bits/s	180 bits/s
Mode S downlink data rate		---	----
NEAN downlink data rate		137 bits/s	339 bits/s

Table 29: Comparison of Data Link User Data Rates (NEAN, AMSS, Mode S)

7.4 Data Transmission Latencies

It was discovered during the performance of the trials that some of the data links worked better in a real flight environment (esp. Mode S). This was due to the fact that the laboratory equipment had certain deficiencies which were avoided in real flight. The real flight environment was therefore chosen for the determination of the parameters. Only the AMSS installation suffered from the installed low gain antenna on the aircraft, so that the laboratory results were used instead. In this sense the shown parameters show the best achievable results.

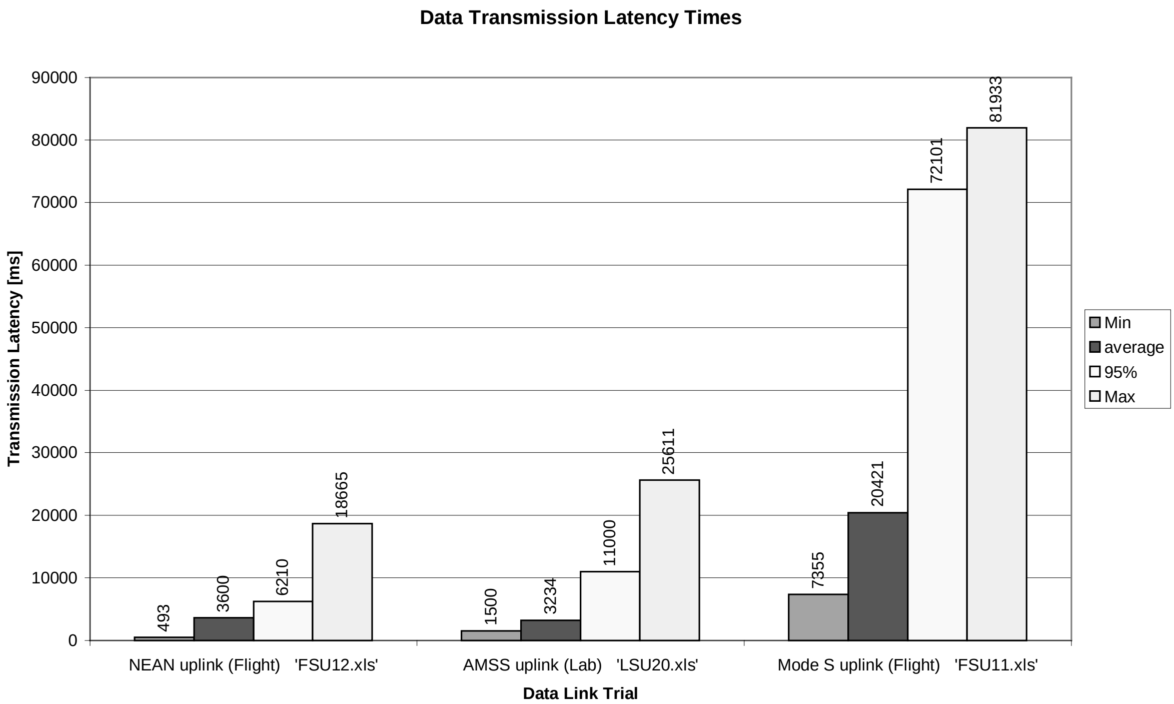

Figure 132: Best achievable Uplink Data Transmission Latencies of the different Data Links

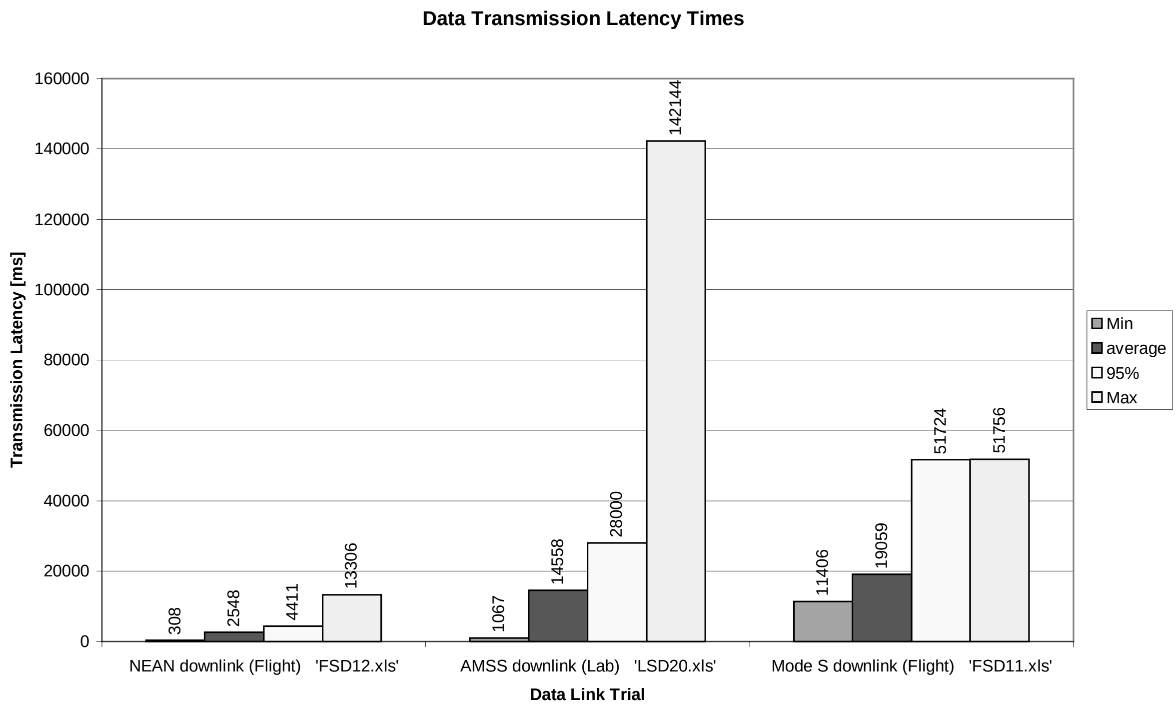

Figure 133: Best achievable Downlink Data Transmission Latencies of the different Data Links

Due to its limitation in terms of message lengths the capabilities of the NEAN data link could only be measured for message lengths between 3 and 39 bytes. In order to be able to compare the data transmission latencies of the NEAN datalink with those of the other two data links the resulting transmission latencies for longer messages up to 1020 bytes were calculated by adding up the average transmission latencies so often as would be required to transfer the 1020 byte messages by several NEAN packets.

Observations	data link: NEAN, AMSS, Mode S		
direction: uplink, downlink	experiment ID: FSU12, LSU20, FSU11, FSD12, LSD20, FSD11	figures: Figure 132, Figure 133	objectives: Comparison of Data Transmission Latencies

1	Figure 132 shows that there is no significant difference between the transmission latencies of the AMSS and the extrapolated NEAN data link. The uplink average data transmission latencies of the AMSS are slightly better than that of the NEAN data link although the 95 % transmission latency values and the maximum values are slightly higher. There is no significant difference in the uplink performance between the AMSS and the NEAN data link.
2	The Mode S Transmission Latency is significantly higher. The average transmission latency is about 6 times as high as for the other data links. The Mode S datalink suffers from the mechanical rotating antenna used in the radar. Alternatively e-scan or sectorised antennae could be used for data link communications so that the transmission latencies could be brought to similar performance as for the other data links.
3	On the downlink (Figure 133) it is visible that the AMSS data link is not as good as the NEAN data link. The Mode S Data link provides similar average performance as the AMSS data link On the downlink the AMSS data link suffers from a more complicated protocol. Especially it is required for the AES to request channel capacity which needs to be granted by the GES prior to its use. Also a higher percentage of message losses needs to be respected on the downlink channel so that the average data transmission latency is increased due to more likely retransmissions. Finally a reduced data rate (1200 bit/s) for the downlink prevented a lower data transmission latency.
4	The Mode S data link is only slightly worse than the AMSS data link. The Mode S data link has a more reliable RF channel and therefore does not loose so much performance on the downlink as AMSS does.

Parameter		**Results**	
		average	**95%**
NEAN Transmission Latency uplink		3 900 ms	6 210 ms
AMSS Transmission Latency uplink		3 234 ms	11 000 ms
Mode S Transmission Latency uplink		20 421 ms	72 101 ms
NEAN Transmission Latency downlink		308 ms	4 411 ms
AMSS Transmission Latency downlink		14 558 ms	28 000 ms
Mode S Transmission Latency downlink		19 059 ms	51 724 ms

Table 30: Comparison of Data Transmission Latencies (NEAN, AMSS, Mode S)

7.5 Application Data Transmission Latencies

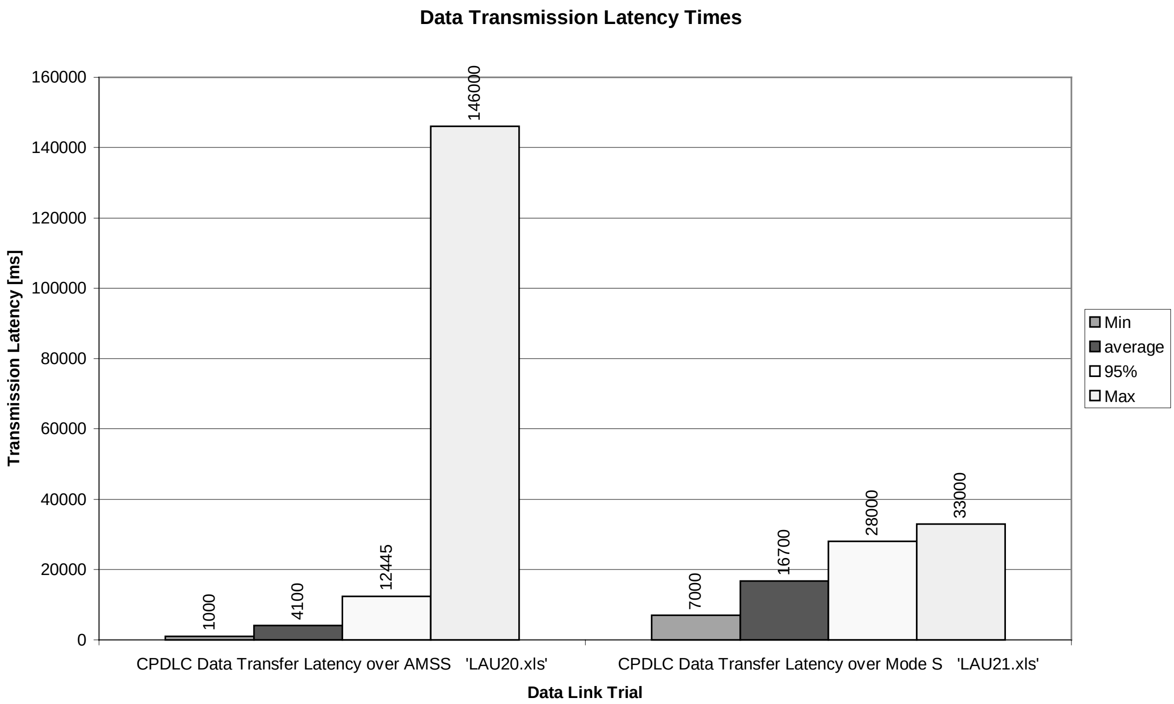

Figure 134: CPDLC Uplink Data Transfer Times over AMSS and over Mode S

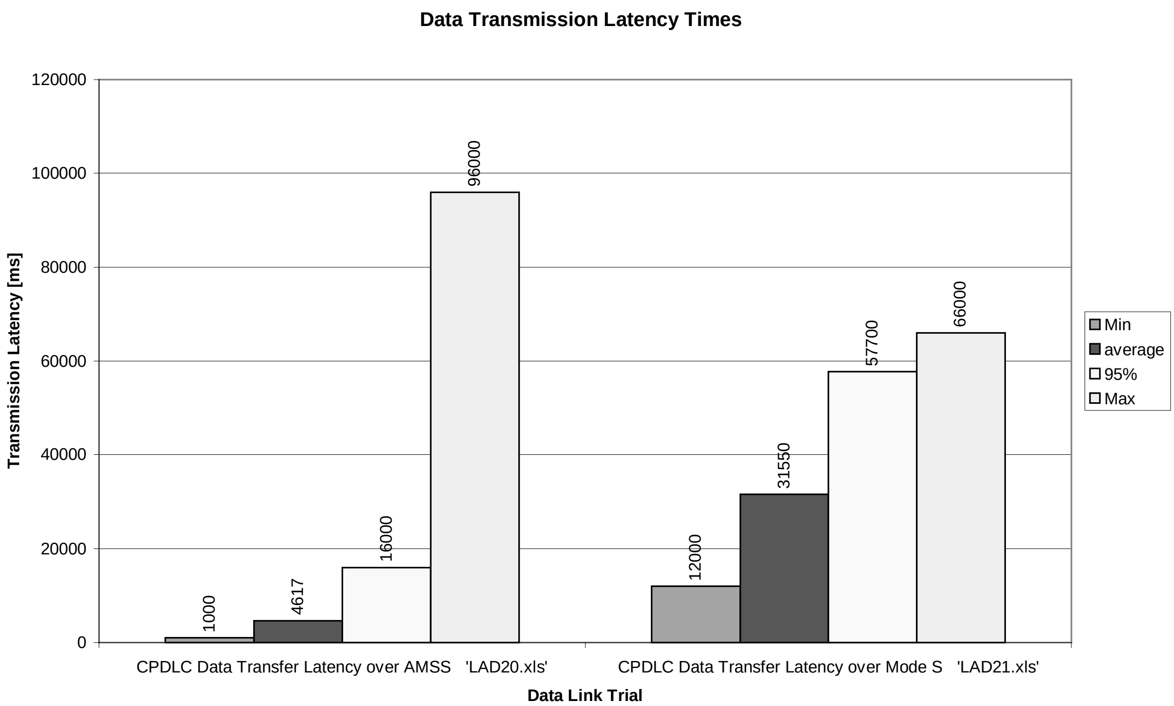

Figure 135: CPDLC Downlink Data Transfer Times over AMSS and over Mode S

Observations	data link: AMSS, Mode S		
direction: uplink, downlink	experiment ID: LAU20, LAU21, LAD20 LAD21	figures: Figure 134, Figure 135	objectives: Comparison of CPDLC Data Transmission Latencies

1 Figure 134 and Figure 135 show that there is a certain advantage of CPDLC over AMSS versus Mode S. However significant exceptions were observed in case of AMSS

Mode S shows significantly higher CPDLC transmission latencies compared to AMSS. This is again caused by the rotating antenna which introduces some extra latency into the system.

Parameter		**Results**	
		average	**95%**
CPDLC uplink over AMSS		4 100 ms	12 445 ms
CPDLC uplink over Mode S		16 700 ms	28 000 ms
CPDLC downlink over AMSS		4 617 ms	16 000 ms
CPDLC downlink over Mode S		31 550 ms	57 700 ms

Table 31: Comparison of CPDLC Data Transmission Latencies (AMSS, Mode S)

7.6 Data Link Loss Rates

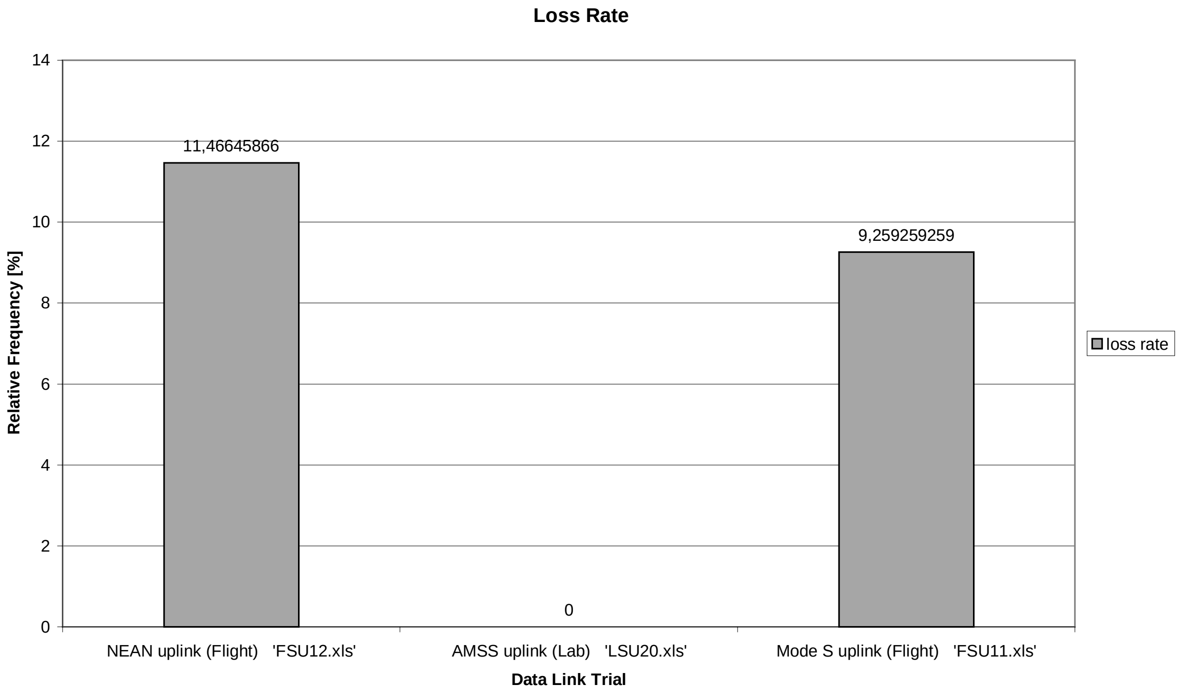

Figure 136: Uplink Message Loss Rates of the individual Data Links

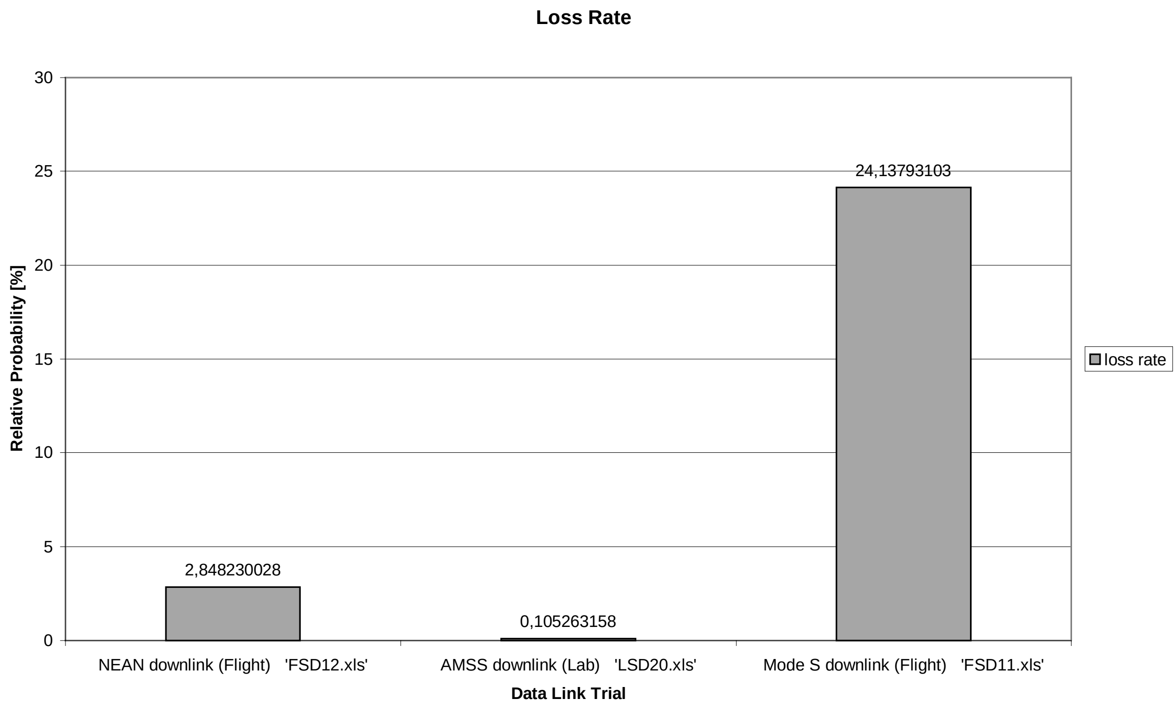

Figure 137: Downlink Message Loss Rates of the individual Data Links

<table>
<tr><td colspan="1">Observations</td><td colspan="2">data link:
NEAN, AMSS, Mode S</td><td></td></tr>
<tr><td>direction:
uplink</td><td>experiment ID:
FSU12,
LSU20,
FSU11,
FSD12,
LSD20,
FSD11</td><td>figures:
Figure 136,
Figure 137</td><td>objectives:
Comparison of Data Transmission Loss Probabilities</td></tr>
</table>

1 Figure 136 shows significant differences of the loss rates of the three data link media. The worst performance was observed for NEAN.

NEAN: NEAN showed the highest message loss rates observed in the trials. For an operational application especially in critical applications this would not be acceptable. Obviously the NEAN data link does currently not provide sufficient protection against data losses. For an operational use it would be essential that a reliable protocol is standardised and implemented to detect any lost packet and to ensure retransmission until all packets are properly delivered. This however had the disadvantage that significantly more channel capacity would be required to accommodate the protection protocol as well as the retransmitted packets so that the operational user data rate would be lower than measured.

AMSS: The best performance in terms of losses was observed with the AMSS data link. During the trials no losses were observed. AMSS implements a reliable protocol including acknowledgements on the RF link. It also implements the X.25 flow control so that an overload potentially causing losses is avoided. AMSS is currently the advanced commercially implemented data link and therefore is best debugged.

Mode S: Mode S also showed a relatively high percentage of losses. However these were primarily caused by malfunctions of the involved experimental systems which caused losses of data due to unexpected connection clearing. Unfortunately these problems could not be solved during the study. It is expected that operational systems will provide the same loss protection as AMSS does. At least the inherent flow control and loss protection features would ensure this theoretically.

2 Figure 137 shows the loss probability of the different data links on the downlink. There NEAN has a much lower probability while Mode S still shows a relatively high percentage of losses.

NEAN: The NEAN datalink also showed difficulties to deliver all packets properly on the downlink but in this case the loss rate was already much smaller than on the uplink. However still a more reliable protection would be required for an operational system.

AMSS: Even AMSS showed losses on the downlink. However these were caused by a yet unknown problem in the AMSS data link.

Mode S: Again a relatively high loss rate is observed. This is also caused by internal faults of the experimental equipment. In an operational implementation such faults would not be expected.

Parameter		**Results**	
		average	

Observations	data link: NEAN, AMSS, Mode S		
direction: uplink	experiment ID: FSU12, LSU20, FSU11, FSD12, LSD20, FSD11	figures: Figure 136, Figure 137	objectives: Comparison of Data Transmission Loss Probabilities
NEAN uplink message loss rate		11,4 %	
AMSS uplink message loss rate		0 %	
Mode S uplink message loss rate		20 421 ms	
NEAN downlink message loss rate		2,8 %	
AMSS downlink message loss rate		0,1 %	
Mode S downlink message loss rate		24,1 %	

Table 32: Comparison of Data Transmission Loss Probabilities (NEAN, AMSS, Mode S)

8 Impact of Results

8.1 Impact of Results on future Data Link Implementations

Based on the measurement results obtained in the data link trials this section provides an high-level assessment of the investigated data link technologies with respect to their suitability in a future operational ATM environment. The methodology selected for this assessment is a comparison of the measurement results with relevant upper bounds established by various sources, such as the ADSP or ODIAC. Assessments are offered for the

- response times required by operational ATS air/ground data communication services (section 8.1.2)
- integrity required by operational ATS air/ground data communication services (section 8.1.3)
- reliability required by operational ATS air/ground data communication services (section 8.1.4)
- throughput required for a typical flight in a data link environment (section 8.1.5).

In order to cope with the large set of and the considerable variation in the measurement results collected during the data link trials, characteristic nominal values are derived in the following section which are used as representative values for the individual data link technologies in the subsequent assessment. Due to the large variations in the measurement sets observed during the data link trials, 95%-values instead of average values are used (where available) as the representative values for the assessment. This approach offers a higher level of confidence in the assessment results.

8.1.1 Measured Values for the Investigated Data Link Systems

Table 33 provides a high-level summary of the measurement results for the three investigated data link technologies. The values listed in this table should be understood as the 95%-values derived from multiple trials in various test environments and are intended to broadly classify the relevant data link technology for the subsequent assessment. The reader is referred to chapters 6 and 7 for the detailed and accurate measurement results.

	AMSS		**Mode S**		**NEAN**	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
User Data Rate (bits/s)[1]	359	180	-	-	312	339
Packet Rate (packets/s)[1]	0,3	0,25	-	-[2]	1,9	2,0
Transmission Delay (seconds)	11,0	28,0	72,1	51,7	6,2	4,4

[1] The data rate and packet rate values are average values collected from a number of measurements with varying packet lengths; therefore no strict relationship exists between the listed values of these two performance characteristics.

[2] No data rate and packet rate could be measured for the Mode S data link; therefore a "-" is indicated in the associated boxes of Table 33.

Message Loss Rate (%)	0,0	0,1	9,2	24,1	11,4	2,8
Reliability (%)	46	42	51	52	56	44
Call Setup Round-trip Time (seconds)	4,7		29,1		n/a	

Table 33: Performance Characteristics of the Investigated Data Links

8.1.2 Response Time Assessment

The response time (see below for a definition) is used as the figure of merit to assess the delay measurement results of the data link trials. As a minimum requirement to support ATM air/ground data services, the two-way transmission delay of a data link system must not exceed the response time listed in the second column of Table 34. The response time values listed in this column are reproduced from [8] and represent the operational requirement for the associated ATM air/ground data communications service in Europe. (For the services which are grey-shaded no requirements have been defined so far).

The columns 4 through 6 of Table 34 indicate whether a given data link system fulfils this requirement for the listed data link services. A click is illustrated in the relevant box if the measurement results for a given data link meet or falls short of the required response time at 95 % probability.

Data Link Service	Response Time (seconds)	Operational Response Time (seconds)	AMSS	Mode S	NEAN
DLIC	tbd	tbd			
ACM	20	120	✓		✓
CIC	20	120	✓		✓
DCL	30	(180) 300	✓		✓
DSC	20	120	✓		✓
D-OTIS	30	60	✓		✓
D-RVR	tbd	tbd			
D-ATIS	tbd	tbd			
CAP	n/a	n/a	✓	✓	✓
ADS	tbd	tbd			
ADS-B	tbd	tbd			

Table 34: Assessment of Data Links w.r.t. Required Response Time

The response time values listed in the second column of Table 34 above are taken from [8] and represent the operational requirement for the associated ATM air/ground data communications service in Europe.

The ***response time*** is defined as the maximum end-to-end time from the moment a message is issued by the originator to the communication system and the moment the logical response (i.e. a LACK message or an error message) is received by the originator from the communication system.

The response time includes two components: (1) the two-way transmission delay of the communication system and (2) the processing time of the received incoming message and the generation of the associated response by the receiving process. It is sensible to assume that in a realistic air/ground environment the former component contributes to a large degree to the overall response time, whereas the portion of the processing time is small compared to the two-way transmission delay.

The operational response time values listed in the third column of Table 34 above are taken from [8] and represent the operational requirement for the associated ATM air/ground data communications service in Europe.

The ***operational response time*** is defined as the maximum end-to-end time from the moment a message is issued by the originator to the communication system and the moment the operational response (e.g. CIC downlink message) is received by the originator from the communication system. It is sensible to assume that the actual transmission delay contributes only to a small fraction to the overall operational response time, whereas the majority of this time interval is used by the receiving entity (e.g. controller or pilot) to generate the appropriate operational response. Therefore, the operational response time is not the appropriate measure to assess the suitability of air/ground data links for ATM air/ground data communications services and has been included in Table 34 above for completeness only.

From the response time assessment in Table 34 it can be concluded that the AMSS and NEAN data links are in a position to support a range of data link services or, more specifically, all data link services for which response time requirements have been defined so far. The Mode S data link fails to meet the defined requirements and can only be considered for non-time-critical data link services, such as CAP.

8.1.3 Integrity Assessment

The integrity requirements established by the ICAO ADSP are used as the figure of merit to assess the packet loss rate measured in the data link trials. The integrity is defined as a communications system’s capability to protect transferred data from alteration, manipulation, loss or destruction caused either by unauthorised entities or system-internal functions.

The integrity values listed in the second column of Table 35 are reproduced from [9] and represent the operational requirement for end-to-end integrity of data link service in support of ATS applications. As a minimum requirement to support ATS data link services, the packet loss rate of a data link system must not exceed these values. The columns 3 through 5 of Table 35 indicate whether a given data link system fulfils this requirement for the listed data link services. A click is illustrated in the relevant box if the measurement results for a given data link meets or falls short of the required integrity at 95 % probability.

Data Link Service	End-to-End Integrity	AMSS	Mode S	NEAN
DLIC	10^{-6}	✓		
ACM	10^{-7}	(✓)		

CIC	10^{-7}	**(✓)**		
DCL	10^{-7}	**(✓)**		
DSC	10^{-7}	**(✓)**		
D-OTIS	10^{-6}	✓		
D-RVR	10^{-6}	✓		
D-ATIS	tbd	**(✓)**		
CAP	tbd	**(✓)**		
ADS	10^{-7}	**(✓)**		
ADS-B	10^{-7}	**(✓)**		

Table 35: Assessment of Data Links w.r.t. Required Integrity

Considering the integrity requirements defined by ADSP and the measurement results collected during the data link trials, it can be noted that none of the investigated data links seems to be robust enough in order to meet the defined integrity requirements on the network level. However, it should be noted that the ADSP requirements refer to the end-to-end integrity, i.e. between applications hosted in end systems. This means that appropriate measures in the upper protocol layers of these end systems, such as checksums and sequence numbers on the transport layer and/or the application layer, may considerably improve the measured integrity on the network layer; experience and analysis [10] shows that integrity improvements in the order of several decades are achievable.

Consequently, the AMSS data link which has demonstrated an excellent loss rate in the uplink (i.e. 0 %, see Figure 136) and a modest loss rate in the downlink (i.e. 0,1 %, see Figure 137) classified in Table 35 above to meet at least the 10^{-6} end-to-end integrity requirement, given that such upper layer protocol mechanisms are applied. It may also meet the 10^{-7} requirement, however this requires a more detailed analysis. (That’s the reason why the click is shown in brackets in Table 35).

The very high loss rates measured for the NEAN and Mode S data links (11,4 % and 24,1 % respectively, see Figure 136 and Figure 137), however, do not allow to arrive at the same conclusion w.r.t. the achievable end-to-end integrity as for the AMSS. This means that these data links are currently not expected to meet the integrity requirements postulated for the known air/ground applications, given the obtained measurement results. However, it should be noted that the observed high loss rate for the Mode S data link seems to be primarily caused by malfunction of the experimental equipment used in the data link trials. It is expected that operational Mode S equipment will exhibit a much smaller loss rate, which in combination with appropriate upper layer loss protection features may qualify this data link for support of air/ground ATS applications.

The high loss rate measured for the NEAN data link seems to be a system-inherent feature which may be attributed to the missing flow control mechanisms in this data link. If such flow control mechanisms are added, e.g. in the context of an ISO/IEC 8208 packet layer interface, and upper layer protection features are also implemented, then the NEAN data link is expected to be a candidate for supporting operational air/ground ATS applications (in the scope of the ADSP integrity requirements).

8.1.4 Reliability Assessment

Although no explicit measurement campaign was included in the data link trials to investigate the reliability of the data links, this chapter tries to make an assessment of the investigated data links w.r.t. this to this feature based on the obtained measurement results.

The reliability of a system is defined as the probability that the system will operate within a given performance range (i.e. deliver a defined level of quality) for a given period of time under specified operating conditions.

The deviation of the measured 95% value maximum from the measured average value as compared with the measured 95% value is used as the reliability metric. This metric is calculated over all measurements campaigns performed during the data link trials according to the following formula:

Reliability metric = $$\frac{1}{n} \cdot \sum_{i=1}^{n} \left(1 - \frac{95\%Value_i - AverageValue_i}{95\%Value_i}\right) \cdot 100\%$$

where n is the number of the performed measurement campaigns.

The reliability requirements defined by the ICAO ADSP [9] are used as the figure of merit to assess the reliability metric calculated from the measurement results of the data link trials. These reliability requirements are listed in the second column of Table 36 and represent the operational requirement for the end-to-end reliability of a communications system in support of ATS applications. As a minimum requirement to support ATS data link services, the reliability of a data link system must not exceed these values. This is due to the fact that the end-to-end reliability is made up of the reliability of the individual systems contained in the end-to-end chain of the communication system; it is the reliability of the weakest element in this chain which determines the end-to-end reliability.

Data Link Service	End-to-End Reliability	AMSS	Mode S	NEAN
DLIC	99,9%			
ACM	99,99%			
CIC	99,99%			
DCL	99,99%			
DSC	99,99%			
D-OTIS	99,9%			
D-RVR	99,9%			
D-ATIS	tbd			
CAP	tbd			
ADS	99,996%			
ADS-B	99,996%			

Table 36: Assessment of Data Links w.r.t. Required Reliability

Considering the reliability requirements defined by ADSP and the measurement results collected during the data link trials, it can be noted that none of the investigated data links seems to be robust enough in order to meet the defined reliability requirements. However, it should be noted that experimental equipment has been used in the data link trials which sometimes exhibited strange/undeterministic behaviour and/or was poorly debugged in some cases.

8.1.5 Throughput Assessment

The throughput assessment is based on a flight communication traffic profile which has been developed in the context of the ATN Implementation Task Force. This flight communication traffic profile is contained in Appendix C of [11] and is reproduced in parts in the Annex E to this report.

Based on this traffic model and assuming an equal distribution of the overall traffic load during a flight, the average number of bits/s exchanged between the ground facilities and an aircraft in support of ATS applications is illustrated in the first and second line of Table 37. The throughput figure in the first line represents the traffic load associated with the ATS application data (i.e. user data) only, whereas the figure in the second line includes the additional overhead caused by a full ATN communication stack. The throughput listed in the third line of Table 37 applies to a flight which uses in addition to air/ground ATS applications AOC/AAC data link services (in an ATN communication environment).

The throughput figures in the second column of Table 37 represent the average throughput requirements per data link channel and are used as the figures of merit to assess the data rates measured during the data link trials. The columns 3 through 5 of Table 37 indicate whether the investigated data link systems fulfil these requirements. A click is illustrated in the relevant box if the measured data rate of a given data link meets or exceeds the required throughput.

Type of Traffic	Throughput	AMSS	Mode S	NEAN
ATS data link services	15,2 bits/s	✓	✓	✓
ATS data link services in an ATN environment	40,3 bits/s	✓	✓	✓
ATS and AOC/AAC services in an ATN environment	48,9 bits/s	✓	✓	✓

Table 37: Assessment of Data Links w.r.t. Data Rates

All investigated data links will be able to transfer the required traffic load per flight associated with the three traffic scenarios considered above. However, it should be noted that the measurements performed during the data link trials and the assessment made above hold for a single aircraft. In an operational environment a number of aircraft will share the capacity of a data link system. Consequently, there will be an upper limit of aircraft which may be simultaneously served by a given ground station. In the case of AMSS, this limit will be defined by the number of channels which may be simultaneously maintained by the ground earth station. In the case of Mode S and NEAN, this limit will be defined by the overall RF capacity offered by the data link system. This overall capacity depends from a number of factors, which are for example the rotation time of the antenna and the geographical distribution of the aircraft in the case of Mode S.

Therefore a more detailed and sophisticated analysis is required to expand the measurement results on a large scale operational scenario.

8.2 Impact of Results for the Aeronautical Telecommunication Network (ATN)

This section assesses the measurement results with respect to potential implications on the implementation of the ATN. In particular, it

- classifies the investigated data link technologies w.r.t. the corresponding ATSC class (section 8.2.1)
- evaluates the performance characteristics of the investigated data link technologies w.r.t. to typical ATN message lengths (section 8.2.2).

8.2.1 ATSC Classification

Subvolume V of ICAO Doc 9705 (i.e. the ATN SARPs) [12] contains a set of transit delay requirements which data link systems have to fulfil in order to qualify for an ATN mobile subnetwork supporting a given ATSC traffic. Eight classes of ATSC traffic are specified in Subvolume 8, where each class is characterised by a maximum tolerable delay (at 95% probability) for the one-way transit of this type of ATSC traffic across a mobile subnetwork. The eight classes of ATSC traffic which, by definition, correspond to eight classes of data links and the associated maximum one-way transit delay is reproduced in the following table.

ATSC Class	Maximum One-way Transit Delay (at 95% Probability) in seconds
A	Reserved
B	3,0
C	5,7
D	10
E	14,5
F	23,5
G	46,5
H	96,5

Table 38: Mobile Subnetwork Transit Delay Requirements

According to this classification scheme, the investigated data link systems can be classified as follows:

Data Link System	ATSC Class
AMSS	E (for uplink traffic), G (for downlink traffic)
Mode S	H
NEAN[1]	D (for uplink traffic), C (downlink traffic)

Table 39: Assessment of Data Link Systems w.r.t. ATSC Class

The assessment reveals that the three investigated data link systems represent different classes of ATN mobile subnetworks according to the classification scheme defined in [12]:

- the NEAN system having a classification of C/D can be categorised as a “middle class system”
- the AMSS being at classification E/G is at the lower edge of the middle class systems
- the Mode S data link is in the lowest ATSC class and consequently only suitable for non-time-critical ATS communications.

It is interesting to note that the three investigated data link technologies cover a large subset of the defined ATSC classes and consequently a broad range of potential ATSC traffic. However, this feature may be a disadvantage in a mixed data link environment; none of the investigated data link systems seems to be a real good backup candidate for one of the other investigated data link systems. In particular, it is hard to imagine that a class H system, such as Mode S, may be an appropriate backup or complementary system for a primary class C system.

8.2.2 Typical ATN Message Lengths

This section evaluates the measured performance characteristics of the investigated data link systems for typical message lengths in an ATN communication environment. In this environment three types of typical message lengths can be observed:

Traffic Type	Typical PDU Length	Example
Uncompressed messages	135 bytes	Initial PDU containing 30 bytes application data Initial IDRP BISPDU
LREF compressed messages	75 bytes	Subsequent PDU containing 30 bytes application data
LREF and Deflate compressed messages	25 bytes	Subsequent PDU containing repetitive header and application data

Table 40: Three Classes of Typical ATN Message Lengths

[1] The classification of the NEAN data link must be considered as hypothetical, as this data link system does not qualify for an ATN mobile subnetwork in its current form. If an ISO/IEC 8208 interface would be added to NEAN data link, then the transmission delay is expected to increase and the current classification has to be revisited.

The following table compares the measured average transmission latency (in seconds) of the AMSS, Mode S and NEAN data link for the three classes of message lengths.

	25 bytes	75 bytes	135 bytes
AMSS uplink	3,1	3,2	3,5
AMSS downlink	3,5	7,8	11,1
Mode S uplink	10,0	11,5	15,2
Mode S downlink	12,5	17,2	20,9
NEAN uplink	0,6	1,3	2,4
NEAN downlink	0,5	1,0	1,9

Table 41: One-way Transmission Latency (in seconds) for Typical ATN Message Lengths

As can be seen from Table 41, the transmission latency grows slightly if the message length increases. The maximum growth rate (i.e. factor 4) can be observed in the NEAN downlink. However this data link has the best absolute transmission latency values which, even for a 135 bytes long message, stay below the latency values of the AMSS and Mode S data link for a 25 bytes long message. The AMSS uplink exhibits the smallest growth rate (i.e. 11%); this means that the transmission delay is almost constant for the three typical ATN message lengths.

In summary, no unusual behaviour of the transmission latency can be observed for all investigated data links. With the potential exception of the Mode S data link, the absolute values of the measured transmission delay for the typical message lengths in the ATN are in an acceptable range.

Table 42 illustrates the measured loss rates of the AMSS, Mode S and NEAN data link for the three classes of message lengths.

	25 bytes	75 bytes	135 bytes
AMSS uplink	0,0	0,0	0,0
AMSS downlink	0,0	0,0	0,0
Mode S uplink	> 0	> 0	> 0
Mode S downlink	> 0	> 0	> 0
NEAN uplink	1,5	5	8
NEAN downlink	0,15	3	5

Table 42: Loss Rate (in percent) for Typical ATN Message Lengths

No complete set of measurement results is available for all three data links. From the available data the following statements can be made:

- The AMSS data link is extremely reliable for all three types of ATN message lengths
- The Mode S data link has a loss rate which is greater than zero and may loss all messages for a limited period of time
- The loss rate of the NEAN data link is not acceptable for ATN communications.

9 Conclusion

Having carefully analysed the large amount of detailed results from the investigated data link systems, it becomes clear that there is no clear winner of the data link trials. All investigated data link technologies exhibit some deficiencies which will limit their deployment for operational data link services. Within the tested environment[1], the major identified deficiencies were:

- The extreme packet loss rate of the NEAN data link in the case that the incoming packet rate exceeds a certain threshold (i.e. more than 3 packets/second) due to the lack of flow control between DTE and DCE and an error detection that withdraws corrupted messages.
- The large variations in the transmission delay of the AMSS data link which may be a problem for data link services which require a request-response transaction being completed within a given time interval
- The high round-trip times of the Mode S data link which exceed the maximum delay expected by the majority of currently envisaged ATS data link services.

9.1 Data Link Technology

Out of the investigated systems, there is no data link technology which suggests itself as a primary candidate for implementation. Based on the assessment presented in this document, AMSS will receive the highest ranking and Mode S the lowest one. However, none of the investigated data link technologies succeeds in meeting the complete set of requirements. In particular, in the categories reliability and integrity the investigated data link systems fall considerably short of the requirements; this may be attributed to the experimental and prototype character of the data link equipment used in the trials.

A lot of trouble arose from Mode S subnetwork component interoperability problems. This was disappointing since more work had been allocated to the systems' interworking, instead of their use.

It is also remarkable that none of the investigated data link systems seems to be a real good backup candidate for one of the other investigated data link systems. In particular, it is hard to imagine that a class H[2] system, may be an appropriate backup or complementary system for a primary class C system.

The AMSS system used for these investigations is already based on commercial products which are on the market for several years. In spite of this, it is even now not in a position to meet all of the requirements. Also the Mode S ADLP, a prototype system which incorporates the experience of several years, entailed various problems; and finally VDL (except Mode 1) is still in its technical infancy.

In conclusion the question arises if any data link may fulfil the stringent operational requirements in the near future.

9.2 Data Link Usage

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[1] The three candidates were tested under different traffic load conditions. While AMSS uses commercial communication channels, the Mode S sensor had to cope with surveillance transactions in parallel. The NEAN tests were performed having 3 channel users as a maximum. Each test result table contains appropriate information.

[2] See ATSC classification in chapter 8.2.1

Due to the immense gap between operational requirements and technical reality, it is obviously still a long way to go for data link system developers and data link providers. But it is as well recommended to re-consider current concepts how data link could be used in the future, in particular with respect to time-critical messages.

We further recommend that work be concentrated on the strong points of the Data Links evaluated during the comparative Data Link examinations and that these be used for the above purpose. These could be the Mode S Specific Services and ADS-B for Mode S, ADS-B for NEAN and data transfer in areas without VHF or radar coverage for AMSS.

Finally, it should be added that the data link investigations exposed a need for recommendations how to classify data links. A case in point is the message length which should be taken into consideration if a data link is classified. For instance, depending on the message length, the AMSS data link (downlink) may be for example an ATSC class C, class D or class E data link (with respect to the ATN classification scheme). Similar effects occur with Mode S and mechanically rotating antennas. This demonstrates that a classification which should provide a basis to compare different data links with each other or to find the adequate data link for a data link service respectively, doesn’t provide a suitable source of help if the results are not presented in conjunction with the measurement procedure they are based on.

9.3 Role of the ATN

The investigations reveal that the ATN and its protocols provide first of all means to optimise the performance characteristics like integrity, reliability and efficiency of data links. In addition, ATN foresees very efficient compression algorithms for the air/ground communication which keeps protocol overhead in an acceptable range. This means that the overhead associated with the protocols above the data link system (which shall guarantee the required reliability and integrity) is in fact only partly seen by the data link system.

9.4 Further Action

Ongoing activities around the introduction of data link into the ATM environment (EU-projects, Eurocontrol projects, national planning) are centered around the use of VDL Mode 2 systems. For this reason, it may be questioned why no VDL Mode 2 data link system had been investigated as well.

Reason was simply that such systems were not available to DFS at the time the activities were conducted. Immediately after the end of the trials, VDL Mode 2 equipment was made available by ARINC, and the analyses described before will be applied to this system as well.

In addition, the before said implies that a demand for more capable data link systems may arise from the applications, and such data link systems will have to be investigated in order to validate their potential use as soon as a reasonable capability for a wider use is acknowledged within DFS.

A Abbreviations:

AAC	Aeronautical Administrative Communications
A-BPSK	Aviation Binary Phase Shift Keying
ACARS	ARINC Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACM	ATC Communications Management
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
ADSP	ADS Panel
AEEC	Airlines Electronic Engineering Committee
AES	Aircraft Earth Station
AM-MSK	Amplitude Modulation Minimum Shift Keying
AMSS	Aeronautical Mobile Satellite Service
AOC	Airline Operational Communication
APC	Airline Passenger Communications
A-QPSK	Aviation Quadrature Phase Shift Keying
ARCAS	ARINC Communications Addressing and Reporting System
ARINC	Aeronautical Radio Incorporated
ASCII	American Standard Code for Information Interchange
ATC	Air Traffic Control
ATIF	ATN Trials InFrastructure
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSC	Air Traffic Service Communication
bps	bits per second
CAP	Controller Access Parameters
CEC	Commission of the European Communities
CET	Central European Time
CIC	Clearances and Information Communications
CLNP	Connectionless Network Protocol
CODECAT	Comparative Data link End-to-end Classification and Analysis Tool
CPDLC	Controller-to-Pilot Data Link Communication

CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
D8PSK	Differentially encoded 8-Phase Shift Keying
DART	Demonstrator and ATN Research Test Bed
Datex P	DATa Exchange by packet-switching
D-ATIS	Digital Aerodrome Terminal Information Service
DCE	Data Circuit-terminating Equipment
DCF 77	German Coded Frequency, 77 kHz (time reference)
DCL	Departure Clearance
DFS	Deutsche Flugsicherung GmbH
DLIC	Data link Initiation Capability
DLS	Data Link Service
DLTE	Data Link Test Equipment
D-OTIS	Digital Operational Terminal Information Service
DPSK	Differential Phase Shift Keying
D-RVR	Digital Runway Visual Range
DSC	Downstream Clearance
DTE	Data Terminal Equipment
EEC	EUROCONTROL Experimental Centre
EIRP	Equivalent Isotropic Radiated Power
EUROCAE	European Organisation for Civil Aviation Electronics
FAA	Federal Aviation Administration
FIS	Flight Information Service
FITAMS	Flight Trials of ATN over Multiple Subnetworks
FMS	Flight Management System
GES	Ground Earth Station
GFSK	Gaussian Filtered Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCI	Human Control Interface
HPA	High Power Amplifier
ICAO	International Civil Aviation Organisation

IEC	International Electrotechnical Commission
INCA	Investigation of Networked CNS/ATM Applications
IRS	Inertial Reference System
ISO	International Organisation for Standardisation
ISU	Initial Signal Unit
LACK	Logical Acknowledgement
LSU	Lone Signal Unit
M-Bit	More-Bit
Mode S	Mode Select
NEAN	North European ADS-B Network
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
nm	nautical miles
OSI	Open System Interconnection
PACK	P-channel Acknowledgement
PC	Personal Computer
PDU	Protocol Data Unit
PES	Pre-Processing & Evaluation Software
PPM	Pulse Position Modulation
pps	packets per second
ProATN	Prototype ATN
PSN	Packet Switched Network
PTT	National Public/Postal Telecommunications Administration
RACK	R-channel Acknowledgement
RAM	Random Access Memory
RFU	Radio Frequency Unit
RQA	Request for Acknowledgement
SARPs	Standards and Recommended Practices
SDU	Satellite Data Unit
SET	Future Technologies & Systems
SITA	Société Internationale de Télécommunications Aéronautiques
SNAcP	Subnetwork Access Protocol
SSR	Secondary Surveillance Radar
SSR	Secondary Surveillance Radar
SSU	Subsequent Signal Unit

STDMA	Self Organising Time Division Multiple Access
SU	Signal Unit
SVC	Switched Virtual Circuit
T-ADLP	Trials-Aircraft Data Link Processor
TAR	Trials ATN Router
TDMA	Time Division Multiple Access
TES	Trials End System
T-GDLP	Trials-Ground Data Link Processor
TP4	Transport Protocol level 4
TRT	Télécommunications Radioélectriques et Téléphoniques
TTS	Trials Transport Server
UTC	Universal Time Coordinated
VDL	Very High Frequency Digital Link
VHF	Very High Frequency

B Glossary:

Integrity: The integrity is defined as a communications system's capability to protect transferred data from alteration, manipulation, loss or destruction caused either by unauthorised entities or system-internal functions.

Latency: The Transit Delay experienced with near-zero loading of communication facilities.

Packet Rate: Measure of the amount of data packets which are processed or transmitted in a certain period (pps).

Transit Delay: Transit Delay is the average transfer delay (as defined in ISO 8348).
In a packet data systems, the transfer delay is the elapsed time between a request to transmit an assembled data packet and an indication at the receiving end that the corresponding packet has been received and is ready to be used or forwarded (ICAO Doc 9705).

Transfer Rate, Bit Rate, Data Rate: Measure of the amount of data which is processed or transmitted in a certain period (bit/s). It describes as well the performance of a network and is dependent from several factors which may have an influence on it:

- used hardware,
- volume of used protocol stacks (and software),
- access method,
- cabling and netload,
- topology, etc.

Reliability: The reliability of a system is defined as the probability that the system will operate within a given performance range (i.e. deliver a defined level of quality) for a given period of time under specified operating conditions.

Response Time: The response time is defined as the maximum end-to-end time from the moment a message is issued by the originator to the communication system and the moment the logical response (i.e. a LACK message or an error message) is received by the originator from the communication system.
The response time includes two components: (1) the two-way transmission delay of the communication system and (2) the processing time of the received incoming message and the generation of the associated response by the receiving proces

Operational Response Time: The operational response time is defined as the maximum end-to-end time from the moment a message is issued by the originator to the communication system and the moment the operational response (e.g. CIC downlink message) is received by the originator from the communication system.

C Observed side effects:

C.1 Mode S

The Mode S subnetwork was faced with a number of individual problems found in the installation. They are explained in the following paragraphs. Since no effort was planned to validate the equipment or identify equipment deficiencies and software bugs, corrective actions could not be taken.

C1.1 Radar

During the tests the DFS SSR/Mode S experimental radar was always working on its limits. It is able to track 128 Mode S targets and has only limited data link capability (only max. 3 Roll-Call periods for data transfer available). An overload processing was included in the internal processing, preventing an overload and crash of the Mode S processor by reducing the surveillance (and data link) coverage. A software upgrade also added a feature to keep a limited number of targets protected from being lost due to the overload processing. Nevertheless, under normal conditions there are in average 180 targets to track, the maximum value was 211. The insertion of 6dB attenuation in the transmitter path did not reduce the target number below 128, i.e. the radar overload processing always was active.

In addition to that, the line of sight between radar and transponder is not optimal. The radar site is about 40 meters higher located than the transponder at a range of 2,5 nautical miles.

C1.2 Transponder

During the tests a TRT transponder was used. The amount of target losses during the trials required also some investigations. The result was the detection of a cable and/or transponder problem. In some cases the 1st two preamble pulses of the XPDR reply were distorted, so the radar could not identify the reply. After a complete reinstallation of the transponder and its connections the situation went slightly better. During further tests the antenna itself and its position were also identified as a cause for the weak RF Link.

The combination of all the above mentioned radar and transponder problems were responsible for causing target losses, re-interrogations, transaction retries and therefore higher transmission latencies as expected.

C1.3 T-GDLP

- *Flow Control*

The data (packet) rate determination should have been performed by injecting messages on a very high rate to see how the system reacts and what is the best data (packet) rate to perform the tests. During these tests the T-GDLP crashed after receiving a Reject packet (due to the weak RF link) from the radar while being in XOFF state. This error was reproducible several times. Under normal circumstances (no Reject) the XON/XOFF flow control was working without any problems. Nevertheless, the above mentioned Reject-case can also happen in an operational environment and should be handled correctly.

- *Uplink Call Set-up*

During the uplink Call Set-up tests the data transfer was interrupted after 128 repetitions. This error has not been investigated, an exact cause could not be found. Possible sources could be the link between T-GDLP and test tool or the equipment itself.

C1.4 T-ADLP

- *Downlink Call Request*

The T-ADLP showed an unexpected Clear during consecutive downlink Call Set-up tests. This Clear appeared mainly after 3 up to 5 complete transactions with a DC=23 decimal. After investigating the T-ADLP log file, an internal message has been found which was different from successful completed Call set-ups (px_st!=NULL). Further investigations proved that the unexpected Clear is caused by an internal pending Clear Confirm in the T-ADLP re-sequencing buffer. This Clear Confirm is in each case “injected” directly after a Call Accept and generates the above mentioned Clear.

- *Downlink data transfer*

The transmission of data packets is interrupted as soon as the transfer of data packets larger than 128 byte started. The test tool divides the large packet correctly into 2 packets, including the correct M-Bit setting. The first and second packet are transferred to the T-ADLP and can be traced on the ARINC link. In the T-ADLP log files only the first packet can be found, the second data packet disappears somewhere in the T-ADLP. Since the T-ADLP is “waiting” for the second packet, it does not generate a RR, but the test tool is waiting for the RR before transferring new packets to the T-ADLP and the system hangs.

C.2 AMSS

Further analysis of the statistical outliers were undertaken to find answers for the following questions:

- What is the size of the transmitted protocol and user data packets that are transmitted via the data link ?
- Is the data transmission influenced by the exchange of routing and protocol information which is transmitted as well via the data link ?

For this purpose, additional tests were performed and the trace functionality of the Trials ATN Router (TAR) was used to record the exchange of protocol and user data packets between air and ground.

C.2.1 Packet size analysis using CPDLC

The first analysis dealt with the CPDLC-start service (dialogue establishment) and CPDLC-end service (dialogue release). It becomes evident that in addition to the data packets generated by the CPDLC application, (protocol-) information is exchanged as well between air and ground systems which is not visible to the user. This exchange is illustrated in Figure 138. The size of the user data and protocol packets exchanged is shown in Table 43. In this connection the effect of the deflate and LREF compression algorithm is noteworthy: If a sequence of bytes in a data packet is to be transmitted by the ATN router, an abbreviation is stored. Every time this sequence appears again, it is replaced by this abbreviation and is further compressed by the LREF compression algorithm which results in a remarkable data compression. Recurrent data sequences could be NSAP addresses, protocol information or similar user data. In the case of a TP4 connection request packet, a reduction from 120 bytes to 17 bytes is possible for TP4 connection requests that follow the first request.

Conclusion: In summary 9 Protocol Data Units (PDUs) with a total amount of 118 bytes are exchanged to establish a CPDLC dialogue and to release it if data compression (deflate + LREF) is used.

A second analysis focused on the transmission of CPDLC user data over the air-to-ground link.

At first view (see Table 44), the CPDLC user data doesn't seem to influence the size of packets exchanged via the data link and that this influence is caused by protocol information (overhead). This is only partly correct. The reason can be found again in the deflate compression algorithm which replaces already known data sequences by shorter sequences as described before. The data exchanged for this analysis was built up by an increased character string which contains the characters transmitted before plus three new characters (1AB, 2ABCDE, 3ABCDEFGH, 4A....). Consequently most of the data unit was already known by the ATN router and could be replaced (compressed) by an abbreviation.

Conclusion: It is assumed that a similar compression behaviour could be achieved in an operational CPDLC environment due to the standardised CPDLC message set.

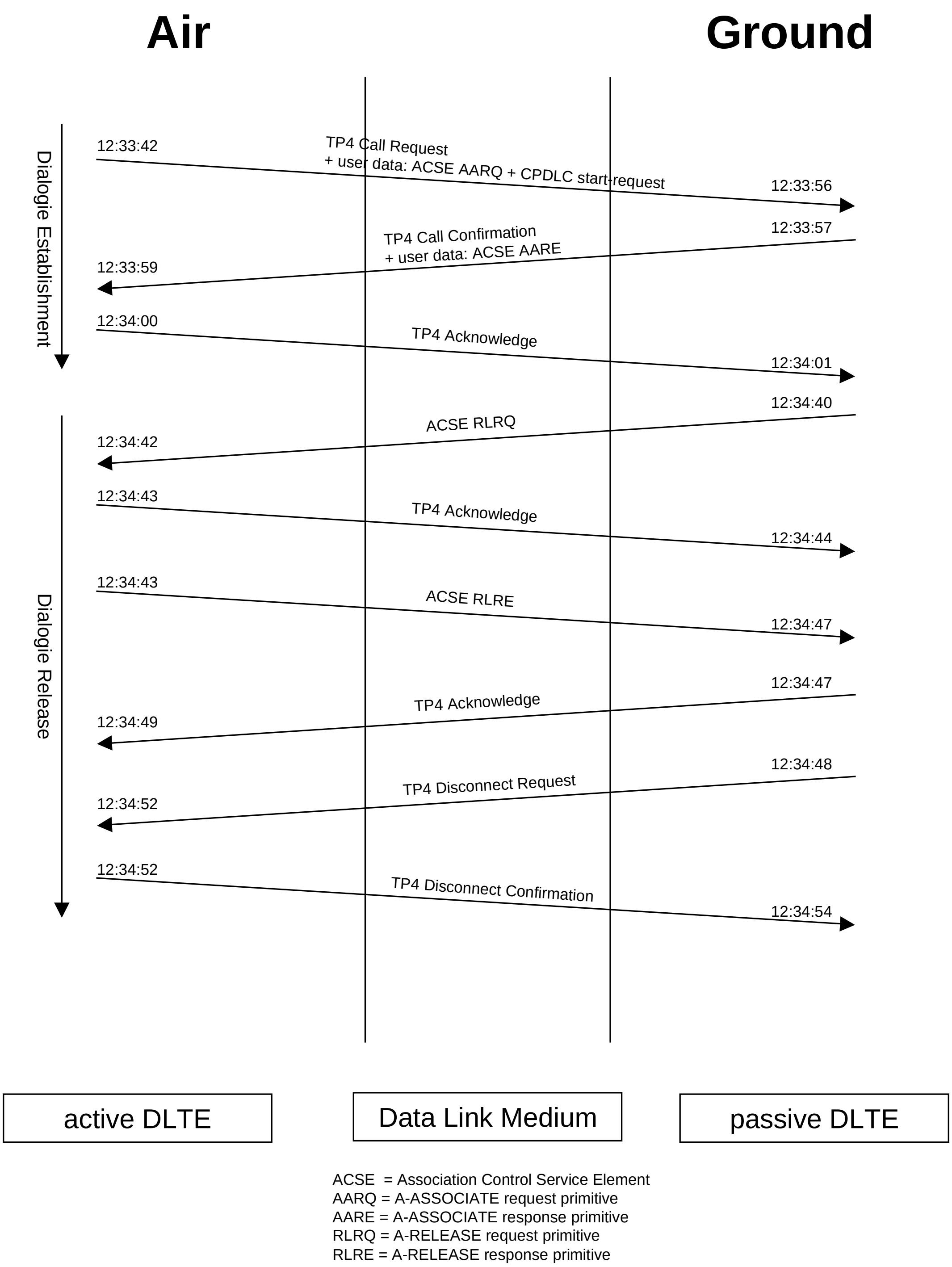

Figure 138: Communication sequence of an air-initiated CPDLC dialogue establishment and a ground-initiated dialogue release

The size of the different X.25 PDUs exchanged during an air-initiated CPDLC dialogue establishment and a ground-initiated dialogue release are shown in Table 43. Each X.25 PDU consists of user data or protocol information, overlaying protocol overhead like

CLNP (ISO layer 3c), TP4 (ISO layer 4), etc. and 3 bytes X.25 protocol overhead (ISO layer 3a).

	X.25 PDU size [bytes]			
data packet	**test run 1**	**test run 2**	**test run 3**	**test run 4**
TP4 Connect Request + user data (ACSE AARQ, CPDLC start-req.)	3 + 120	3 + 17	3 + 17	3 + 17
TP4 Connect Confirmation + user data (ACSE AARE)	3 + 56	3 + 14	3 + 15	3 + 14
TP4 Acknowledge	3 + 14	3 + 12	3 + 12	3 + 12
ACSE RLRQ	3 + 18	3 + 13	3 + 13	3 + 13
ACSE RLRE	3 + 17	3 + 13	3 + 12	3 + 13
TP4 Disconnect Request	3 + 14	3 + 13	3 + 14	3 + 13
TP4 Disconnect Confirmation	3 + 13	3 + 12	3 + 12	3 + 12

Table 43: X.25 PDU size of exchanged packets during a CPDLC-start service and CPDLC-end service dialogue

The following packet size was measured during the transmission of CPDLC data packets:

	X.25 PDU size [bytes]			
data packet	**test run 1**	**test run 2**	**test run 3**	**test run 4**
1AB	3 + 27	3 + 19	3 + 19	3 + 19
2ABCDE	3 + 25	3 + 19	3 + 19	3 + 19
3ABCDEFGH	3 + 28	3 + 19	3 + 19	3 + 19
4ABCDEFGHIJK	3 + 27	3 + 18	3 + 19	3 + 19
5ABCDEFGHIJKLMN	3 + 28	3 + 19	3 + 19	3 + 19
6ABCDEFGHIJKLMNOPQ	3 + 29	3 + 20	3 + 20	3 + 20

Table 44: X.25 PDU size for a CPDLC-message service data exchange

C.2.2 Outlier analysis

Due to the fact that during the connection establishment and release experiments as well as during the data transmission experiments extreme outliers of up to 70 seconds occurred, a third analysis was carried out to investigate the flow of data via the AMSS data link. As an result, three explanations can be given:

- *crossing PDUs*

Based on the TAR trace it was possible to prove the negative impact of crossing PDUs (e.g. IDRP packets or TP4 Acknowledges) on the data transmission latency.

One example is the outlier shown in Figure 139 which occurs during a data transmission experiment:

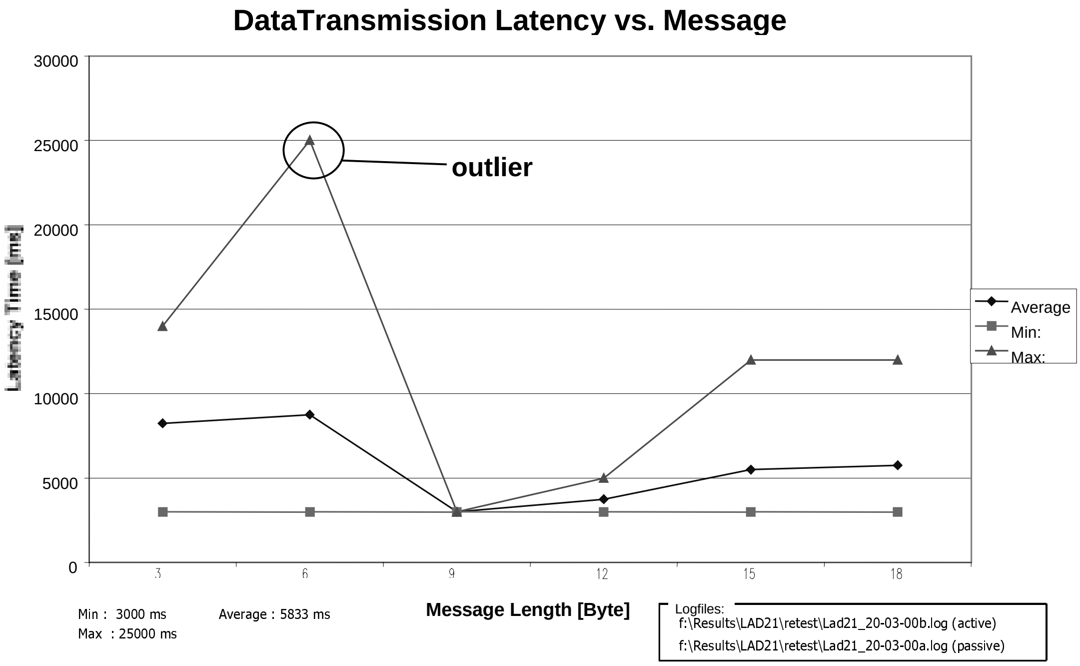

Figure 139: Outlier occurred during a data transmission experiment

An analysis of the PDUs exchanged during a data transmission experiment showed that after every second CPDLC data packet a confirmation (a TP4 acknowledge) was generated and sent out by the receiver.

One exception was the TP4 acknowledge packet sent out at 13:10:15 by the airborne DTE (see Figure 140). This TP4 acknowledge packet was no confirmation of successful data transmission but the result of a TP4 protocol setting called „TP4 Window Timer“. This timer is responsible for the periodical exchange of a Flow Control Configuration Parameter which keeps the TP4 window information topical.

The answer to this TP4 acknowledge packet, which was sent from ground to air, appeared exactly when a CPDLC data packet was transmitted from air to ground.

While it is unclear which involved system (e.g. AES, GES, ATN router) had a problem with crossing PDUs, it is obvious that it had an impact on the data transmission behaviour of the overall AMSS data link.

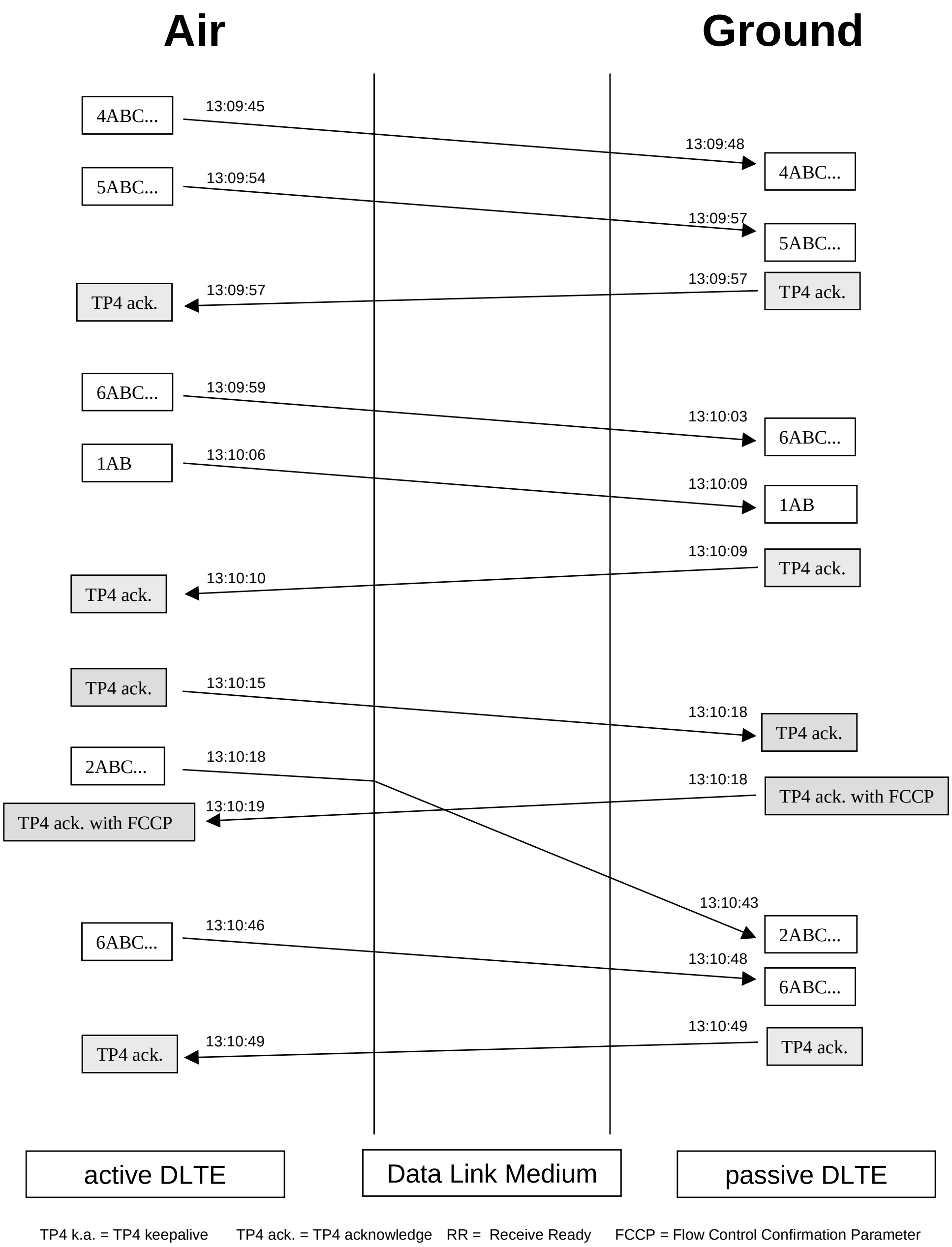

Figure 140: Communication sequence of an air-to-ground data transmission using CPDLC

- *R-Channel*

Further outliers that occurred in the scope of the CPDLC-start request (dialogue establishment) experiment (downlink) shown in Figure 141 couldn't be traced back to crossing PDUs. However it is noteworthy that the prevailing part of the transmission latency was caused by the TP4 Call_Request PDU. This PDU was transmitted via the AMSS R-channel (downlink) which is not very reliable. In the scope of [5] Eurocontrol found that more than 10 % of transmissions via the R-channel require retransmissions. This result could be confirmed.

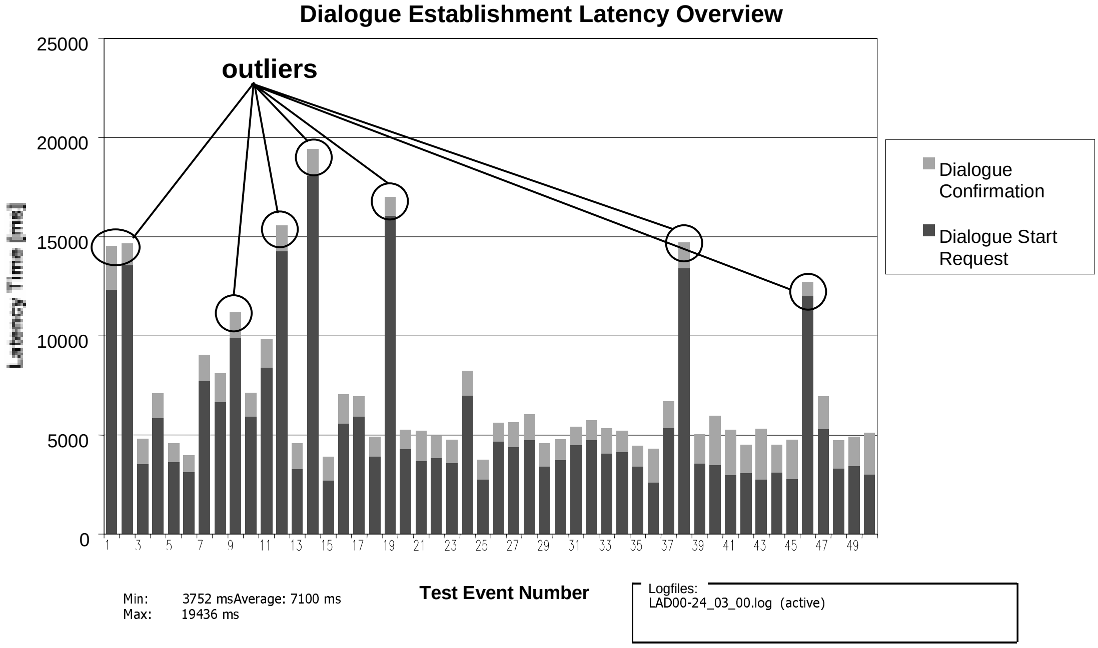

Figure 141: Results of a dialogue establishment experiment (downlink) with several outliers

- *Traffic load*

It was not possible to reproduce outliers of 50-70 seconds like they occurred during the first experiments within the scope of the three additional experiments performed in March 2000. However, measurements performed on different days reveal a dependency of the data transmission latency on the traffic load (which is of course not surprising).

In most cases, independent of the day when the experiment was performed, it took only 5-7 seconds to establish a CPDLC dialogue, but irregularities could be observed in the frequency and intensity of the outliers which varied between 15 and 70 seconds. It was out of the scope of these comparative data link investigations to analyse satellite or GES traces but it is assumed that these irregularities are caused by varying traffic load on the AMSS channels.

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E Flight Communication Traffic Profile

ATS Data Link Services

Based on an analysis of the communication requirements of

- the ODIAC data link services performed in [13]
- additional future ATS data link services performed in [14] and [15]

the following typical communication characteristics per data link service can be derived:

DataLink Service	Transactions Per Flight	Messages Per Transaction	Message Size (Bytes)
ATC Communications Management (ACM)	6	8	15
Departure Clearance (DCL)	1	6	40
Clearances and Information Communications (CIC)	16 (every 5 minutes)	6	38
Downstream Clearance (DSC)	2	8	31
Aircraft Parameter Reporting (APR)	40	1	10
Controller Access Parameters (CAP)[1]	40	1	9
Data Link Operational Terminal Information (D-OTIS)	2	3	50
Data Link Runway Visual Range (D-RVR)	2	4	15
Data Link Initiation Capability (DLIC)	5	4	25
Pushback Clearance request/delivery	1	4	20
Taxi request/delivery	1	4	20
Automatic Dependent Surveillance	78 (every minute)	1	25

Table 45: Typical Communication Parameters of ATS Data Link Services

[1] The CAP service which will deliver current aircraft parameters (such as heading, speed) to ground controllers in real-time is expected to be provided through non-ATN-compliant data communications, such as Mode S specific services.

AOC/AAC Data Link Services

Based on an analysis of the AOC/AAC communication requirements performed in [16] the following typical communication characteristics per data link service can be derived:

Data Link Service	Transactions Per Flight	Messages Per Transaction	Message Size (Bytes)
Movement Messages (OOOI)	4	1	40
Aircraft and Engine Performance/Trend Monitoring	3	1	100
Flight Status Reports (ETA, Delays, Diversions, Progress Reports)	5	1	80
Automatic Terminal Information Service (ATIS)	2	3	50
Fuel Status	2	1	40
Load Sheet Transfer	1	1	80
Flight Plan Transfer	1	2	200
Flight Log Transfer	1	2	100
Dispatch/Weather Reports	2	1	80
Crew and Aircraft Schedule	1	1	100
Maintenance Items	1	1	100
Service Messages	2	2	100
Quality Monitoring	2	1	50
Cabin Log Book Transfer	1	1	400
Real-time Maintenance Information	1	5	50

Table 46: Typical Communication Parameters of AOC/AAC Data Link Services

F Description of used systems:

Component: **Air Router**		
Parameter	**Value**	**Version/Date**
Hardware:	PC Pentium 100, CE_200 ARINC Board	
Manufacturer/ Organisation:	TAR: Vertel TES : Thomson FITAMS: Vertel	
Operating System:	Sun Solaris	2.5.1
Applications	TAR-TTS, TAR-TTS Steps TAR-TTS Tools TES, TES Tools FITAMS CPDLC	Release ID E.01.20Oct98, Release ID E.01.20Oct98, Release ID E.01.20Oct98, Release ID C.01.23Sep98, Release ID C.01.23Sep98, 5.02.20Nov898
Configuration:	TAR: Ar429confconfig.sdu satcom_priority low satcom_speed high satcom_suplex half TAR: Dart.idrp holdtime 900 retransmissiontime 120 defretryinterval 120 defretrylimit 2 defmaxcredit 2 TAR: Dart.tp4 inactime 600 initretrans 60 windowtime 120 maxretrans 3 locackdelay 30 flowctrlint 30	
Startup Scripts:	TAR: Dart.start TES startup FITAMS startup	
X.121 Address (Laboratory)	Mode S: 1711516400 AMSS: 011115171151418	

Component: **Air/Ground Router**		
Parameter	**Value**	**Version/Date**
Hardware:	HP Workstation HP X.25 Adapter Board	C110 9000
Manufacturer/ Organisation:	Vertel TES: Thomson FITAMS: Vertel	
Operating System:	HP UX STREAMS package FILESET SX25-COM FILESET SX25-IP FILESET SX25-PA	B.10.20 9000/777 10.20 Rev.7.9 25Aug98 10.20 Rev.7.9 25Aug98 10.20 Rev.7.9 25Aug98
Applications	TAR-TTS, TAR-TTS Steps TAR-TTS Tools TES, TES Tools FITAMS CPDLC	Release ID E.01.20Oct98, Release ID E.01.20Oct98, Release ID E.01.20Oct98, Release ID C.01.23Sep98, Release ID C.01.23Sep98, 5.02.20Nov898
Configuration:	TAR: Dart.idrp holdtime 900 retransmissiontime 120 defretryinterval 120 defretrylimit 2 defmaxcredit 2 TAR: Dart.tp4 inactime 600 initretrans 60 windowtime 120 maxretrans 3 locackdelay 30 flowctrlint 30	
Startup Scripts:	TAR: Dart.start TES startup FITAMS startup	
X.121 Adresse (Laboratory)	Mode S: 002 AMSS: 45610353011	

Component: **Air Testtool**		
Parameter	**Value**	**Version/Date**
Hardware:	PC Pentium II, 300 MHz ARINC-429, 2RX, 2 TX, 16kB Board	
Manufacturer/ Organisation:	CIMS GmbH	
Operating System:	SUN Solaris	2.6
Applications	DLTE	1.1.1
Configuration:	Transmitrate: low Receiverate: low	
SAL:	253 (AMSS), 224 (Mode S)	
X.121 Address (Laboratory)	AMSS : 011115171151418 Mode S: 1711516500	
X.121 Address (Flight)	AMSS : 011115220401570 Mode S: 2204015700	
NEAN Transponder Address (Lab)	TESTLAN4	
NEAN Transponder Address (Flight)	PH-LAB00	

Component: **Ground Testtool**		
Parameter	**Value**	**Version/Date**
Hardware:	PC Pentium II, 300 MHz X.25 Board Netcom Highway "AB-57IP"	
Manufacturer/ Organisation:	CIMS GmbH	
Operating System:	SUN Solaris	2.6
Applications	DLTE	1.1.1
Configuration:	X.25 packet size: 128 X.25 window size: 2	
X.121 Address (Laboratory)	AMSS: 026245610353011 Mode S: 002	
X.121 Address (Flight)	AMSS: 026245610353011 Mode S: 002	
NEAN Transponder Address (Lab)	@EDDFB01	
NEAN Transponder Address (Flight)	@EDDFB01	

Component: **Satellite Data Unit**		
Parameter	**Value**	**Version/Date**
Hardware:	MCS 3000	
Manufacturer/ Organisation:	Racal Honeywell	
Data rate (downlink, laboratory trials)	R-channel: 1.200 bps T-channel: 1.200 bps	
Data rate (uplink, laboratory trials)	P.channel: 10.500 bps	
Data rate (downlink, flight trials)	R-channel: 600 bps T-channel: 600 bps	
Data rate (uplink, flight trials)	P.channel: 600 bps	

Component: **NEAN GNSS Transponder**		
Parameter	**Value**	**Version/Date**
Hardware:	T2/R2/MXP 3501	
Manufacturer/ Organisation:	GP&C Sweden AB	
Operating System:	RTX	
Applications:	software version 14.0 mobile	
Configuration:	Serial port: 9600 bps transmitter power: 5W no of text message retries: 3 delay for re-transmission: 500 ms	
Startup Scripts:	N/A	
Transponder ID	Langen Transponder: TESTLAN1 Aircraft Transponder: PH-LAB00	

Component: **NEAN GNSS Base Station**		
Parameter	**Value**	**Version/Date**
Hardware:	T3	
Manufacturer/ Organisation:	Saab Dynamics AB	
Applications:	software version 3.1/F	
Configuration:	Serial port: 19200 bps transmitter power: 5W no of text message retries: 5 delay for re-transmission: 500 ms see related document [13] for more details	
Startup Scripts:	N/A	
Transponder ID	@EDDFB01	

Component: **NEAN Local Server**		
Parameter	**Value/Version**	**Version/Date**
Hardware:	PC PENTIUM 100 MHz, 80 MB RAM	
Manufacturer/ Organisation:	BIT-Computer	
Operating System:	Windows NT	4.0, SR 3
Applications:	LS/SDS	V4.12
Configuration:	see related document [13]	
Startup Scripts:	N/A	

Component: **CISCO ROUTER**		
Parameter	**Value**	**Version/Date**
Hardware:	CISCO 2501	
Manufacturer/ Organisation:	CISCO	
Operating System:	CISCO IOS, 11.0	11.0
Applications:	N/A	
Configuration:	cisco_edla.txt (for the router in Langen) cisco_eddf.txt (for the router in Frankfurt)	
Startup Scripts:	N/A	

Component: **Mode S Transponder**		
Parameter	**Value**	**Version/Date**
Hardware:		
Manufacturer/ Organisation:	TRT	
Operating System:	Firmware	BS7 Fitams
Applications:	N/A	
Configuration:	Mode S Level 4	
Start-up Scripts:	N/A	
Address	3C9A74 {HEX}	

Component: **T-ADLP**		
Parameter	**Value**	**Version/Date**
Hardware:	PC ARINC 429 Board	
Manufacturer/ Organisation:	EUROCONTROL / TUB	
Operating System:	Free BSD (Unix)	
Applications:	T-ADLP SW	
Configuration:	ISO 8208: ARINC 429 high speed	
Start-up Scripts:	see Applications	

Component: **Mode S Radar**		
Parameter	**Value**	**Version/Date**
Hardware:	Experimental Mode S Station Data link extension	
Manufacturer/ Organisation:	Thomson-CSF, Frankreich	
Operating System:	N/A	
Applications:	Mode S Datalink	
Configuration:	Antenna Rotation Time 10 s (6 rpm)	
Start-up Scripts:	manually parameterised	

Component: **T-GDLP**

Parameter	**Value**	**Version/Date**
Hardware:	Processor: Motorola Computer Group Radio Clock: Radiocode Clocks Ltd. Watchdog: ETC Group	
Manufacturer/ Organisation:	Logica/Thomson	
Operating System:	UNIX System V/88 Release 4.0, V 4.3; VMEexec Real Time OS	
Applications:	Mode S T-GDLP SW	7.0
Configuration:	uif_configuration.txt wancfg23.gdlp wancfg45.gdlp	
Start-up Scripts:	see Configuration	
SSE DTE address:	010	

G List of experiments:

ID	Experiment	Objective	Data Link	Application
LSU00	**Connection Establishment Data Link Uplink**	- Connection Establishment latency, - Availability.of Connection Establ.	AMSS	N/A
LSU01	**Connection Establishment Data Link Uplink**	- Connection Establishment latency, - Availability of Connection Establ.	Mode S (ISO 8208)	N/A
LSU10	**Bitrate Data Link Uplink**	- Bitrate	AMSS	N/A
LSU11	**Bitrate Data Link Uplink**	- Bitrate	Mode S (ISO 8208)	N/A
LSU12	**Bitrate Data Link Uplink**	- Bitrate	NEAN	N/A
LSU20	**Data Transmission Data Link Uplink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	AMSS	N/A
LSU21	**Data Transmission Data Link Uplink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	Mode S (ISO 8208)	N/A
LSU22	**Data Transmission Data Link Uplink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	NEAN	N/A

Table 47: List of Data Link Laboratory experiments (Uplink)

ID	Experiment	Objective	Data Link	Application
LSD00	**Connection Establishment Data Link downlink**	- Connection Establishment latency, - Availability of Connection Establ.	AMSS	N/A
LSD01	**Connection Establishment Data Link downlink**	- Connection Establishment latency, - Availability of Connection Establ.	Mode S (ISO 8208)	N/A
LSD10	**Bitrate Data Link downlink**	-Bitrate	AMSS	N/A
LSD11	**Bitrate Data Link downlink**	-Bitrate	Mode S (ISO 8208)	N/A
LSD12	**Bitrate Data Link downlink**	-Bitrate	NEAN	N/A
LSD20	**Data Transmission Data Link downlink**	- Data transmission latency - Data Integrity - Availability Data Transmission	AMSS	N/A
LSD21	**Data Transmission Data Link downlink**	- Data transmission latency - Data Integrity - Availability Data Transmission	Mode S (ISO 8208)	N/A
LSD22	**Data Transmission Data Link downlink**	- Data transmission latency - Data Integrity - Availability Data Transmission	NEAN	N/A

Table 48: List of Data Link Laboratory Experiments (Downlink)

ID	Experiment	Objective	Data Link	Application
LAU00	**Connection Establishment Application uplink**	- Connect. Establ. latency - Availability of Connection Establ.	AMSS	CPDLC
LAU01	**Connection Establishment Application uplink**	- Connect. Establ. latency - Availability of Connection Establ.	Mode S (ISO 8208)	CPDLC
LAU20	**Data Transmission Application uplink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	AMSS	CPDLC
LAU21	**Data Transmission Application uplink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	Mode S (ISO 8208)	CPDLC

Table 49: List of Application Laboratory Experiments (Uplink)

ID	Experiment	Objective	Data Link	Application
LAD00	**Connection Establishment Application downlink**	- Connect. Establ. latency - Availability of Connection Establ.	AMSS	CPDLC
LAD01	**Connection Establishment Application downlink**	- Connect. Establ. latency - Availability of Connection Establ.	Mode S (ISO 8208)	CPDLC
LAD20	**Data Transmission Application downlink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	AMSS	CPDLC
LAD21	**Data Transmission Application downlink**	- Data transmission latency - Data Integrity - Availability of Data Transmission	Mode S (ISO 8208)	CPDLC

Table 50: List of Application Laboratory Experiments (Downlink)

ID	Experiment	Objective	Data Link	Application
FSU10	**Data Transmission Data Link Uplink**	- Data transmission latency - Availability Data Transmission - Data Integrity	AMSS	N/A
FSU11	**Data Transmission Data Link Uplink**	- Data transmission latency - Availability Data Transmission - Data Integrity	Mode S (ISO 8208)	N/A
FSU12	**Data Transmission Data Link Uplink**	- Data transmission latency - Availability Data Transmission - Data Integrity	NEAN	N/A

Table 51: List of Data Link Flight Experiments (Uplink)

ID	Experiment	Objective	Data Link	Application
FSD10	**Data Transmission Data Link downlink**	- Data transmission latency - Availability Data Transmission - Data Integrity	AMSS	N/A
FSD11	**Data Transmission Data Link downlink**	- Data transmission latency - Availability Data Transmission - Data Integrity	Mode S (ISO 8208)	N/A
FSD12	**Data Transmission Data Link downlink**	- Data transmission latency - Availability Data Transmission - Data Integrity	NEAN	N/A

Table 52: List of Data Link Flight Experiments (Downlink)