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ATN PROJECT

Proposed ACARS Replacement Solutions

ATN Ref. : DED6/ATNCT/ProATN_Sup/DCI/AW_22

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Rev. No. : Issue 1.2

Date : 24/03/98

DOCUMENT CONTROL LOG

SECTION	DATE	REV. NO.	REASON FOR CHANGE OR REFERENCE TO CHANGE
	24/03/98	Issue 1.2	

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1. Introduction

1.1 Scope

This paper is concerned with the development of an architecture for the ACARS upgrade to VDL Mode 2. Two approaches are considered - an X.25 minimalist approach, and an ATN Approach. The development implications, benefits and risks of the preferred approach are also discussed.

1.2 Purpose of Paper

The purpose of the proposed paper is as an input document to the AEEC in order to consider the alternative approaches to ACARS upgrade.

1.3 References

1. Air-Ground Services Datalink Network Transition (SITA - VL/LP/002/Jul 14/1997)

2. ACARS X.25 Internetwork Protocol Presentation to AEEC Datalink User Forum 27 Jan 98 (SITA - Philip Clinch)

3. ACARS to VDL Transition Plan Presented to AEEC Datalink User Forum 27 Jan 98 (ARINC - Aloke Roy - Jan 23/98)

2. Summary

ACARS needs to be upgraded to give significant additional capacity to its users. That is now an accepted fact, and that upgrade needs to happen quickly. Two approaches to this upgrade have been tabled - one essentially from SITA and the other from ARINC. The SITA proposal is a minimalist approach aimed solely at replacing VHF ACARS with VDL Mode 2 and does not consider the future development of air/ground communications. On the other hand, the ARINC proposal additionally includes components of the ICAO ATN and, by implication also considers the need for transition to ATN based communications for both AOC and ATC users.

In order to illustrate the technical differences between the two proposals, Figure 2-1 below attempts to capture the two proposals as protocol stacks, and to contrast them with the existing ACARS protocol stack and the ATN protocol stack

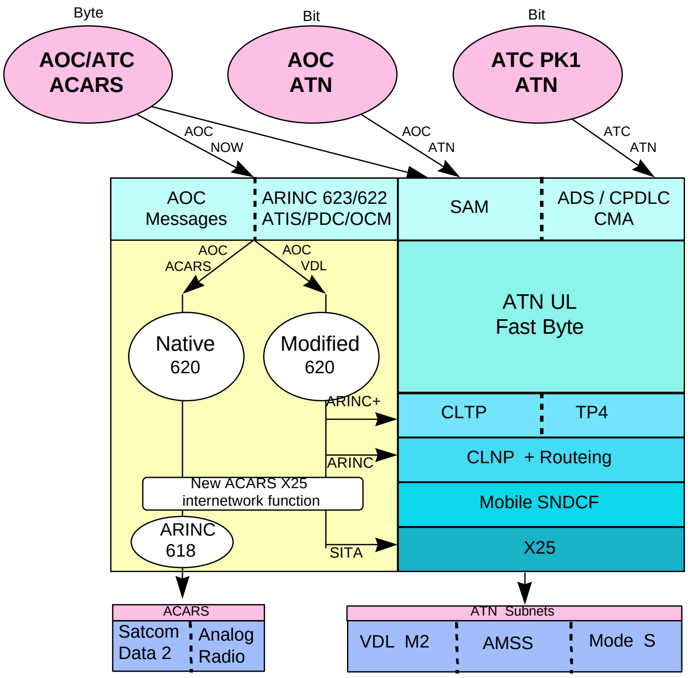

Figure 2-1 The Proposed Architectures

VHF ACARS is a character mode communications protocol whilst the ATN provides for binary mode communications, as does VDL Mode 2. All the proposed solutions involve some sort of “cross-over” between these stacks, so that character mode ACARS can make use of the binary VDL Mode 2. As shown in the figure (and described below) there are three suggested possibilities for this “cross over”:

- SITA: at the VDL Mode 2 Network Access Service (X.25 compliant service)
- ARINC: at the CLNP Internet Service level
- ARINC + (i.e. Enhanced): at the Connectionless Transport Service Level

In the medium and long term co-existence between the Byte oriented applications and the bit oriented ATN network and subnetworks may be provided by Simple ATN Messaging

(SAM), thus avoiding the need for such cross-overs. However, the cross-over is the essential feature of any transition solution

2.1 SITA Proposal

The **basic characteristics** of the SITA proposal are:

- Transmission of AOC/ATC ACARS messages over VDL Mode 2 via Enhanced ARINC 620 (and ACARS X25 Internetworking Function) directly over X.25 with no ATN Internet functionality.
- Continued use of ARINC 620 format for compatibility with current ACARS implementation,
- Enhancement of ARINC 620 to :
  - provide a non-ATN internetworking functionality on the ground (DSP) and in the aircraft in addition to current message handling functionality,
  - support current byte-oriented application data using VDL bit-oriented transmissions rather than ACARS,
  - support an 'ACARS Transparency Function '(ATF) that provides new bit-oriented over VDL Mode 2 using ACARS like messages.
- As a next step , a modern transport protocol is advised on top of the X.25 layer and ARINC 620, and TCP/IP is mentioned as a candidate .

The **Advantages** of the proposal are that:

- Provides the required increase in datalink capacity to satisfy demand by 2000
- Supports Legacy ACARS Applications

The **Disadvantages** of the proposal are that:

- The new protocols and procedures proposed by SITA are not standardised or yet specified (publicly) and would need to be developed.
- All traffic would be forwarded to the DSP (Singapore in the SITA case) where it would be split and sent to AOC and ATC destinations. This implies a single point of failure.
- The proposal Is not at all targeted at the final goal of ATN datalink communications, the only common point is the use of X.25 (although the way X.25 SVCs are used is different). Transition to ATN would be hindered.

2.2 ARINC Proposal

The **basic characteristics** of the ARINC proposal are:

- Transmission of AOC/ATC ACARS messages over VDL Mode 2 using the ATN CLNP protocol via Subnetwork Dependent Convergence Facility (SNDCF) and X.25.
- Continued use of ARINC 620 format for compatibility with current ACARS implementation,

- Use of CLNP without ATN transport,
- Use of CLNP without ATN Routing,
- Use of CLNP without the Mobile SNDCF but the standard fixed SNDCF.

The **Advantages** of the proposal are that it:

- Provides the required increase in datalink capacity to satisfy demand by 2000
- Supports Legacy ACARS Applications
- Has already been validated in prototypes and trials due its basis in the ICAO ATN, whilst maintaining compatibility with existing character oriented links,
- Allows the deployment of Air-ground Routers to separate and forward independently AOC and ATC traffic with no single point of failure
- Provides the required increase datalink capacity to satisfy demand by 2000,

The **Disadvantages** of the proposal are that it:

- Proposes the non-use of the Mobile SNDCF and thereby looses the compression available in that function (LREF compression), this means that the CLNP header would always be transmitted over the datalink wasting bandwidth,
- Proposes direct use of CLNP without transport, removing the reliability added by Transport,
- Proposes direct use of CLNP without transport, which means that multiple applications above the stack could only be addressed by multiple NSAPs,

2.3 ARINC+ Proposal

This is an enhancement of the original ARINC proposal made by Eurocontrol, amongst others, in order to avoid the perceived disadvantages. In order to do this, this proposal introduces:

- The ATN Mobile SNDCF in order to gain compression benefits
- The use of the CLTP in order to provide for data integrity checks and to provide an equivalent addressing mechanism to that currently provided by the ARINC 618 “label”, with extensibility to other applications.

2.4 The Best Way Forward

Each proposal requires modifications to the airborne and ground infrastructure. The ARINC proposal is firmly on the path to internationally agreed and standardised ATN architecture; the SITA approach requires much more modification to achieve that goal.

There is an urgent need for extensible implementation enabling transition from current ACARS -based transmissions towards more performant digital mechanisms such as VDL Mode 2, whilst maintaining backward compatibility with existing AOC and infrastructure. ATN technology is mature. ATN systems work today over digital subnetworks (in ADS Europe and the Eurocontrol ATN Trials Infrastructure). Certifiable/Operational ATN components are in production (PROATN/ATNSI) and should be used in the short term to avoid interim solutions which will incur great expense to modify or upgrade in the medium and long term.

Onboard coexistence of several “stacks” and standards should be minimised. However, dynamic switching between ACARS and ATN subnetworks (e.g. VDL Mode 2) is required when an aircraft flies across the boundary of an ACARS and VDL Mode 2 region. Certifying and implementing dual stack in avionics will not be easy, alternative approaches involving a third option may be impossible due to avionics capacity limitations.

Any approach that requires additional interim steps on the path to ATN will be very expensive in the medium and long term and should be avoided, especially as ATN development already makes available a considerable amount of validated specification and working software that could be utilised for AOC purposes..

From analysis it seems that the best way forward for short term implementation would be to adopt the ARINC+ approach, and that is the recommended approach.

The remainder of this paper is devoted to analysis of the requirements for the ACARS upgrade, how each of the two major proposals (SITA and ARINC+) meet those requirements, and the development implications of the ARINC+ requirement. A draft Transition Plan for the ARINC+ strategy is also considered.

The result of the detailed analysis supports the above conclusion. The SITA proposal is workable but is likely to be more complex to implement than has been envisaged and does not appear to consider longer term evolution of air/ground communications. It is also an “X.25 everywhere” solution that does not readily accommodate new networking technologies. Transition to the ATN has to be accommodated within the near future and, given the length re-equipage cycles of aircraft, it is not acceptable to not accommodate ATN transition within this upgrade.

3. Requirements Analysis

3.1 Background

ACARS is too popular for its own good. For example, in North America, ACARS system demand has been growing at a rate of 12 to 15 per cent per annum, and will double in five years. However, the number of frequencies available to ACARS is limited - a subset of the 760 25 kHz channels available in the Aeronautical VHF Band - and given the demands on placed on this band, there is unlikely to be space for any more ACARS channels. While ACARS can also use the Inmarsat AMSS Data 2 service, this also has a limited capacity. This growth is thus taking place in a very resource limited area and there will soon cease to be capacity to meet demand.

The rapid growth in demand for ACARS services exceeds the 5-7% annual growth rate in Air Movements because:

- the increase in the number of frequency of flights which force airlines to increase the level of automation in their ground systems and require a direct datalink to aircraft to maximise efficiency;
- the increase in automation of aircraft systems (e.g. a Boeing 777 generates four times as much traffic than older aircraft);

and this can only get worse as increased use of ATC automation is introduced.

Faced with such facts, it is clear that a strategy is needed to make available improved data link capacity.

There is certainly room for improvement. In today's terms, ACARS makes very poor usage of the available channel capacity. The modulation scheme used provides a channel data rate of only 2400 bps. Furthermore, channel access uses the Carrier Sense Multiple Access (CSMA) procedure in order to resolve access contention. CSMA is always in-efficient as, under CSMA, the access time to the channel grows exponentially as the demand increases, and ACARS uses a particularly inefficient version of CSMA with long sense times. It has been calculated that in areas of high VHF datalink usage, the ACARS CSMA algorithm provides a user data capacity of no more than 300 bps.

3.2 VDL Mode 2

VDL Mode 2 is one of a series of ICAO VHF data communications specifications that has been designed to give improved performance over ACARS. VDL Mode 2 uses the same channel size as ACARS, but provide a much improved modulation scheme than the simple Amplitude Modulation used by ACARS - Differentially encoded 8-Phase Shift Keying (D8PSK) is used instead and this operates at a bit rate of 31.5 kbps. Although CSMA is also used by VDL Mode 2, the version of the algorithm used is also much more performant than the versions used by ACARS.

It is expected that the user data capacity with VDL Mode 2 will be 10kbits/s compared with the 300 bits/s of ACARS.

As an ICAO data link, VDL Mode 2 provides an X.25 Network Access Service to its users. The service is thus a reliable connection mode service.

VDL Mode 2 is the natural successor to ACARS. It uses the same channels but offers much improved capacity. Although there are other VDL Modes under ICAO standardisation, only VDL Mode 2 is likely to be available in the timescale for ACARS replacement.

However, it is not a “drop in” replacement for ACARS. It’s X.25 service is too different from “Plain Old ACARS” for this to be possible. Furthermore, a drop in replacement is not necessarily desirable as the ARINC 618 air/ground protocol is also inefficient - especially for binary communications - and should also be replaced.

3.3 Other Air/Ground Data Links

Although VDL Mode 2 is seen as the natural replacement for ACARS, there are other air/ground data links becoming available which can also be of use to airlines. These include a data link service using HF frequencies and Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites. The HF datalink should follow ICAO practice and provide an X.25 data link. However, LEOs are provided by commercial organisations and may use more modern access methods, such as B-ISDN using the Asynchronous Transfer Mode. It should also be possible to accommodate such data links in the ACARS replacement architecture.

3.4 ATN Status

The ICAO Aeronautical Telecommunications Network (ATN) has been validated by the ICAO ATN Panel and will be included in Annex 10 of the International Civil Aviation Treaty. It has been validated using an extensive program of prototypes and trials, including in-flight trails such as the very successful ADS Europe. As a technology, it has been proven both in the laboratory and in trials and is ready to move to operational use. Certified products for airborne use are now being developed for ATNSI.

Implementation of the ATN will be necessary to support the automation of Air Traffic Management that will be essential if the current rate of increase in air movements continues at its current rate. There is no alternative to the ATN to providing the reliable, high availability, high integrity and certifiable data communications necessary to support such features. Such automation has to be brought in early in the next decade and, for example, the need to implement the ATN is included in Eurocontrol’s ATM 2000+ Strategy, which requires ATN implementation by 2005. Indeed, the indications are that this date needs to be brought forward.

The ATN is not so much a networking technology as a strategy for integrating many different network types to provide a reliable, high availability, high integrity data communications service.

3.5 ACARS Upgrade Requirements

An increase in the capacity provided by VHF ACARS is essential and VDL Mode 2 is the only available air/ground data link that can meet this requirement. The principal requirement is that the VHF ACARS service is upgraded to use VDL Mode 2. In addition:

1. The ACARS service must be upgraded without affecting the end user service. There must be no change required to the interface to airlines and any changes to take advantage of improvements other than increased capacity should be discretionary for each airline.

2. The airborne interface must also be unchanged. During the transition phase, while VDL Mode 2 is introduced, both services will need to be supported by upgraded aircraft with a seamless transition from one mode of use to the other.

3. ACARS already includes a satellite based data link and HF services are being introduced. The ACARS upgrade must accommodate networks other than VDL Mode 2 with again a seamless transition from one network to the other.

4. The re-equipage timescale for the introduction of VDL Mode 2 into aircraft overlaps with the necessary introduction of the ATN. Transition to the ATN must therefore be accommodated within any ACARS upgrade strategy.

4. Upgrade Candidates

Two alternative approaches to the upgrade of ACARS to use VDL Mode 2 technology have been proposed, together with associated variants. The first approach, which has been championed by SITA, is predicated on the replacement of the existing ARINC 618 Air/Ground Character Oriented Protocol and the ACARS modulation scheme by VDL Mode 2 and its X.25 derived communications service. The second approach, which has been proposed by ARINC together with variations from Eurocontrol and ACI (the so called ARINC+), enhances the SITA proposal by including the use of ICAO ATN protocols and procedures. These approaches are presented and analysed below.

4.1 Proposal #1: ARINC 618 to X.25

Note: the following description is based on various papers and inputs, and aims to develop what has been proposed into a workable solution identifying where development work needs to be done.

The proposed approach is understood to be essentially minimalist in intention, the aim being to upgrade ACARS to VDL with least disruption to the end-user service and the existing implementation. As a consequence, a relatively painless transition is also hoped for. However, the transition is not as simple as just upgrading the ground stations and airborne radios.

VDL Mode 2 has been specified as an ICAO air/ground data link and the specification has accepted current ICAO practice in that it provides a connection mode X.25 “end to end”[1] communications service. On the other hand, the existing ARINC 618 and the ACARS transmission scheme provides an acknowledged connectionless service. This mismatch itself implies a significant change.

Under VDL Mode 2 an aircraft’s communications equipment and/or a ground station must recognise that they are within range of each other and then perform the procedures needed to establish a switched virtual circuit (SVC). Messages can then be sent over the SVC, with the underlying protocol responsible for message segmentation/reassembly and retransmission in case of error. The SVC provides a continuous association between the aircraft and a ground station until either the aircraft goes out of range, a handover procedure is used to pass the SVC to another ground station, or the SVC is explicitly terminated.

Under classic ACARS operation, the communications media is simply a broadcast communications channel with a simple CSMA procedure used to minimise simultaneous transmissions. A message formatted according to ARINC 618 is broadcast over this channel and potentially received by all aircraft and ground stations within range. However, the transmission includes both an aircraft address (its registration mark or Flight Number) and a ground station identifier, and only the addressed destination will actually receive the message - the rest ignore the message.

The change to VDL Mode 2 thus implies a major change in the way the air/ground data link is managed. SVCs need to be established in advance of communication and messages routed over the appropriate SVC.

Most of the ARINC 618 functionality is also replaced by the SVC approach, but not all. It will still be necessary to transport the “label” information (essentially a form of sub-addressing) and provide for the delivery acknowledgement. The need for a delivery acknowledgement may surprise some readers as X.25 is intended to provided a reliable communications

[1] Between the two ends of the data link - not end user to end user.

service. This is true, but only up to a point. While the service is end-to-end across the X.25 network, the protocol is not. The X.25 packet layer protocol operates over a single data link only and acknowledgement of delivery at the X.25 packet layer is delivery to the network only and not to the network user. X.25 itself, does have an end-to-end delivery confirmation facility (the "D-bit"). However, this is not necessarily available with VDL Mode 2.

The replacement of the character mode 618 functionality by a binary transport function also permits the development of an "ACARS Transparency Function" for transport of binary FANS-1/A messages. However, this has been ruled out of the current work by the AEEC as it implies changes to the FMS in additional to the communications equipment.

To implement the proposed solution will require:

- An update avionics (CMU) implementation, including "dual stacks" to support a gradual deployment of VDL Mode 2.
- The development of an ARINC 620/618 to VDL Mode 2 Message Gateway
- The development of VDL Mode 2 SVC management procedures
- The deployment of VDL Mode 2.

4.1.1 Proposed Airborne Architecture

Figure 4-1 illustrates the perceived impact on the Avionics architecture from the SITA proposal. The shaded functions are existing functions, whilst the heavily shaded functions are modified functions. Unshaded functions are new.

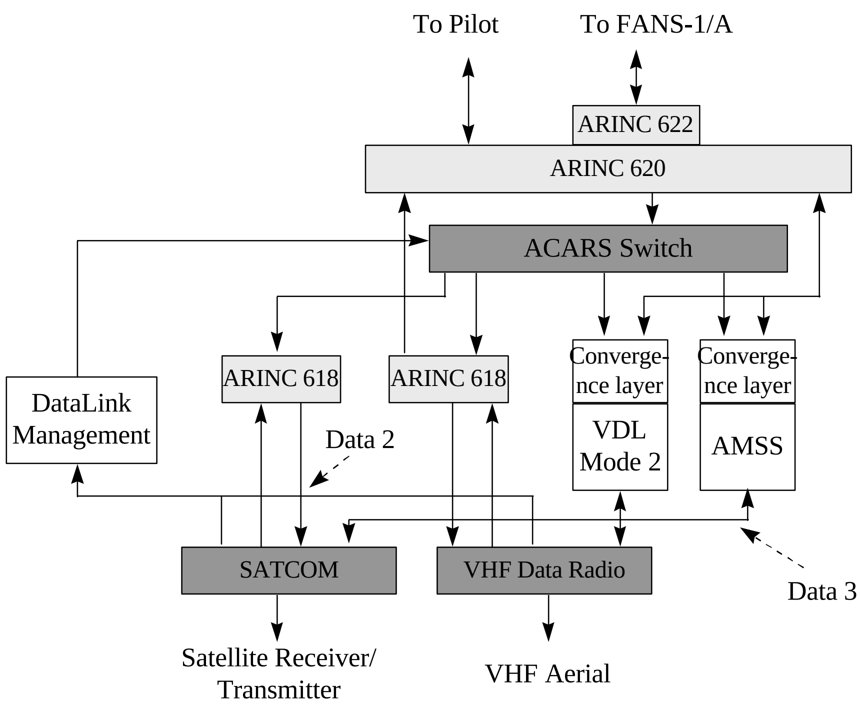

Figure 4-1 Airborne Architecture (Derived from SITA Proposal)

The existing ARINC 620 message service is assumed to be retained. This provides messaging services to the pilot and, through the ARINC 622 function, to FANS-1/A systems.

The existing (albeit undocumented) functionality that decides between the VHF and Satcom services will need to be modified in order to choose between the alternative communications stacks: the alternatives include VDL Mode 2, AMSS and “Plain Old ACARS” (POA). They may also include the HF data link. This ACARS Switch function must choose between the active communications links. This may include multiple concurrent VDL Mode 2 SVCs with different Ground Stations and satellite ground stations, and POA Ground Stations. It is probable that VDL Mode 2 and POA VHF Ground Stations will not be available concurrently unless the VHF Data Radio can support concurrent use of two different modulation schemes. It will need to have access to up-to-date network availability information from a Data Link Management function.

The ACARS Switch function will need to route each message individually, taking account of local information on data link availability and local preferences expressed as some sort of Routing Policy.

If the choice is POA, then the message is encapsulated according to ARINC 618 and a further route choice is made (as at present) for either SATCOM Data 2 or VHF ACARS.

If the choice is AMSS Data 3 or VDL Mode 2, then the ARINC 618 service semantics will need to be mapped to the CLTP. This function is identified here as the “Convergence Layer”. The message is then sent over the appropriate virtual circuit.

Note: such a “Convergence Layer” is not explicitly specified in the SITA proposal, instead a modified ARINC 620 is proposed. Such a modification is expressed here as the “Convergence Layer”, and a different Convergence Layer may be required for each type of data link.

Incoming messages arrive over a given data link and then are passed eventually to the ARINC 620 messaging function.

Longer messages sent over POA must be segmented by the ARINC 618 messaging function. However, those sent over AMSS Data 3 or VDL Mode 2 do not need to be, as this functionality is already provided for in the underlying data links.

4.1.2 Proposed Ground Architecture

Figure 4-2 illustrates an example of how the ground architecture could develop with the SITA proposal.

Unless the service providers modify their DSP implementations to include direct support of VDL Mode 2 and AMSS Data 3, there will need to be some sort of Gateway between the ARINC 620/618 style of operating and the VDL Mode 2/AMSS Data 3 style. Many instantiations of such a gateway could be deployed, and, essentially, the gateway would appear to the DSP as one or more POA Ground Stations. At one extreme, there could be a single gateway co-located with a service provider’s DSP while, at the other extreme, there would a separate gateway co-located with each ground station i.e. one gateway per ground station.

Note: Co-locating the Message Gateway to the extent of combining it with the DSP is the current SITA proposal..

Figure 4-2 illustrates an intermediate case, where a message gateway interfaces several ground stations to the DSP. It communicates over an X.25 public or private network, with the ground stations, and probably over X.25 to the DSP. An X.25 Interworking unit is used to interconnect the air/ground data link with the ground X.25 network (Note that this approach was successfully used in the ADS Europe Trials for AMSS). The X.25 internetworking unit would map the X.25 DTE addresses used for the air/ground datalinks into X.25 DTE addresses compliant with the ground network’s addressing plan.

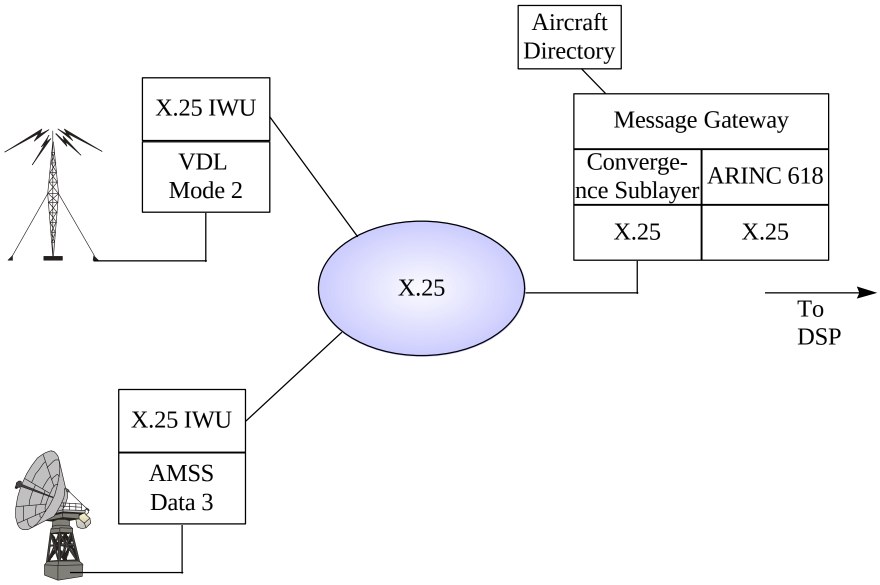

Figure 4-2 Ground Architecture (Derived from SITA Proposal)

The Message Gateway would need to perform the following functions:

- **Message Handling:** whilst many ARINC 620 messages are end-to-end, some are service messages and may have to be actioned in the network. For example, Ground/Ground messages such as "Unable to Deliver Uplink Message" would be generated by the Message Gateway from information received from the Ground Station. The full specification of this gateway will need to specify message handling by SMI.

- **Message Routing:** downlink messages always go to the DSP. However, uplinked messages are addressed to individual aircraft either by registration mark or flight number. The message address will have to be mapped to an existing SVC using the DTE address of the other end of the SVC to identify the aircraft, using some sort of local "Aircraft Directory".

- **Message Acknowledgement:** the message gateway will need to convert message acknowledgements using ARINC 618 procedures into message acknowledgements under the "convergence sublayer" protocol and vice-versa.

The above implies that the message gateway is not transparent to ARINC 620 messages but has to interpret and perhaps generate some message formats. Furthermore, a management protocol is probably necessary between Gateway and Ground Stations. This will be needed to report Ground Station status. The mapping between the Aircraft's Registration Mark/Flight Number will also have to be performed. This may be managed by simply waiting for the first message from an aircraft and using the information contained in it in order to provide the mapping.

4.1.3 SVC Management

Procedures will be necessary in order to determine when SVCs are established and terminated, or passed between ground stations if the VDL Mode 2 handover procedure is supported.

The decision to establish an SVC will be air-initiated. An aircraft can learn of the existence of a VDL Mode 2 Ground Station by receiving its Ground Station Identification Frame (GSIF) and can then decide whether it will use it for data link communications.

Note: it is assumed that an aircraft's VHF Data Radio can receive both POA modulated ACARS squitter messages and VDL Mode 2 GSIFs without manual reconfiguration, so that it can determine whether POA or VDL Mode 2 procedures should be used.

Once the airborne systems have learnt of the existence of a VDL Ground Station, they can initiate an SVC with the Message Gateway. Its DTE address can simply be a well known DTE address that is commonly understood by all VDL Mode 2 Ground Stations. The interworking units will map this well known address into the actual ground X.25 DTE address of the message gateway and map the aircraft's DTE address (derived from its 24-bit ICAO identifier) into the ground X.25 network's address space.

When in range of several VDL Mode 2 Ground Stations, an aircraft may have concurrent SVCs through each of them, to the same or different Message Gateways. This is a local issue and depends upon the functionality of the airborne systems. However, this is a desirable situation, as it allows for essentially a "make before break" type of operation when moving between different coverage areas, perhaps even of different service providers.

Similarly, an aircraft can establish an SVC through AMSS, once it has logged on to a satellite Ground Station, with a Message Gateway.

During the transition from POA to VDL Mode 2, an aircraft may be within range of both VDL Mode 2 and POA Ground Stations. Depending on the capabilities of its VHF Data Radio, it may maintain VDL Mode 2 SVCs and be available to receive (or send) using POA. However, if this functionality is not supported then an internal decision process will need to choose between establishing/keeping VDL Mode 2 SVCs and using POA.

Connection Termination is an issue. To do this in a managed way would require some knowledge of actual aircraft position and intent. This is thought to be impractical. Instead, an SVC will be lost when an aircraft goes out of range of a VDL Mode 2 Ground Station and, if it has not done so already, the aircraft will need to establish a new SVC with a Ground Station already within range.

However, SVC cleardown takes place over a period of time and is not instantaneous. The Ground Station and airborne equipment will separately recognise the communication loss and not necessarily simultaneously. Furthermore, it will take a finite amount of time for the connection loss to be propagated through the ground X.25 network and the further the message gateway is from the Ground Station, the longer this will take.

During this period, any messages sent over the failed SVC will be lost and may have to be retransmitted. It is therefore very important to keep this period as short as possible in order to minimise the impact on end-to-end transit delay and message delivery probability. This argues for the Message Gateway to be close to the Ground Station as this will at least minimise the propagation delay. Furthermore, there is also an issue over the rate at which SVCs are established and terminated. This can have a serious effect on network performance and, again, this effect is limited by keeping the Message Gateway close to the Ground Station.

4.1.4 Multiple SVCs

In response to comments raised by ATC Service Providers, an extension has been proposed to this approach in order to support multiple SVCs i.e. not just SVCs with the Message Gateway, but also with other Ground Systems for ATC purposes.

This is possible, but raises all sorts of problems with respect to SVC management. In particular:

- The airborne Routing Function becomes more complex as it must decide which messages are routed direct to the ATC Provider and which are sent via the DSP.

- How does the airborne system know which Ground DTE Addresses it should contact? The Message Gateway can be located by a "well known" DTE address, but the ATC Provider will vary.

- What is the effect of the additional load of multiple SVCs on VDL Mode 2 and the Ground Network, especially is the rate of establishment/termination is high as the aircraft moves between the coverage of different Ground Stations?

4.1.5 Analysis

The SITA proposal as developed above is believed to be workable - although the extension to "multiple SVCs" may not prove practicable. It will require the development of some sort of Message Gateway and probably a Convergence Sublayer protocol and a Ground Station to Message Gateway Management protocol.

However, it is also a limited approach in that it does not provide for any later transition to ATN and consequentially CNS/ATM - that is other than by complete replacement and the awkward transition that this could imply. Given the timescale for aircraft equipage and the need to introduce CNS/ATM functions in approximately the same timescale, this has to be viewed as a major deficiency. The proposal does not even aim to give significant improvements to the existing FANS-1/A system other than improved capacity.

A clear risk of this approach is that the introduction of CNS/ATM would be compromised with longer timescales being necessary, or airlines would be faced with early replacement of the VDL Mode 2 upgrade with the consequential financial impact this implies. That is it may not be possible to realise the investment in this upgrade before a forced upgrade to CNS/ATM becomes necessary in support of ATC.

4.2 Proposal #2: Use of ICAO ATN Protocols

This proposal can be viewed as building upon the SITA proposal in order to include a transition path to CNS/ATM. The VDL Mode 2 stack is enhanced to include the CLNP, CLTP and the so called "Mobile SNDCF" for use with both VDL Mode 2 and AMSS data 3. This gives the following additional benefits:

- Use of the Mobile SNDCF provides for data compression. Analysis of ADS Europe Trials data showed a compression ratio of better than 3 to 1 achieved with the relatively compact ATC data set. Text based AOC messages may well achieve better compression ratios. Use of this technique could therefore result in significant cost savings to airlines and improve frequency spectrum utilisation.

- Use of CLNP permits the development of a ground network of ATN Routers and the introduction the ATN's Mobile Routing strategy. This would avoid many of the address mapping issues inherent in the SITA proposal and support a smooth transition to a global ATN. Direct communication with ATC providers would be possible without requiring multiple air/ground SVCs with the same VDL Ground Station. Valuable in-service experience would be gained in managing the ground ATN infrastructure, which would be essential for operational ATC services that require a safety case.

- Use of CLTP permits a simplified Convergence Sublayer Protocol and offers the later potential for end-to-end data integrity.

- Avionics vendors would also have the option of including the ATN Dialogue Service and TP4 support to provide reliable connection mode services in support of FANS-1/A. This could make this package more usable and provide the opportunity for other cost/benefits.

4.2.1 Proposed Airborne Architecture

Figure 4-3 illustrates the proposed airborne architecture including an ATN compatible stack. The shading conventions are as for Figure 4-1, with white characters on dark background to indicate those components that are to be available from ATNSI's development.

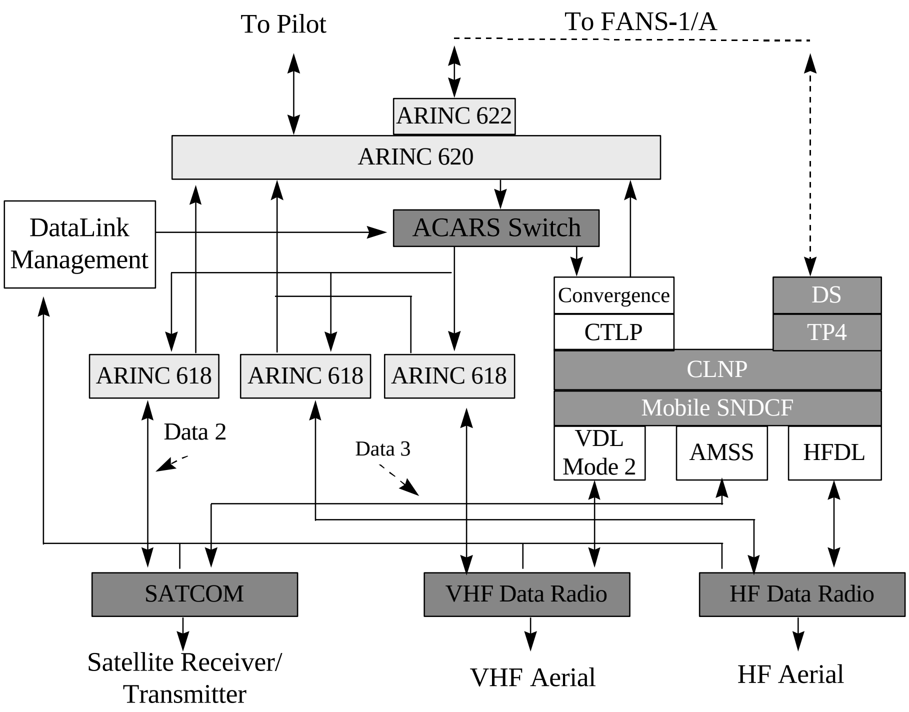

Figure 4-3 Proposed ACARS Upgrade including ATN

With this architecture, the ACARS Switch is a straight choice between POA and ATN communications services, with the decision probably dependent on availability of communications services alone. When the message takes the ATN Route then a preference order of air/ground data links can be passed with the message, if required by local policy. A second routing decision takes place in the forwarding process of CLNP, in order to choose between available air/ground communications paths. This decision follows the ICAO specification and would depend on data link availability and the preference order requested.

The architecture introduces the ATN's Mobile SNDCF for use with both VDL Mode 2 and AMSS. It would also be used with other air/ground data links, such as the HF data link. The SNDCF is essentially the procedures for managing the use of the SVCs over the various air/ground data links and including data compression functionality.

The Connectionless Network Protocol (CLNP) is the user of the Mobile SNDCF and provides the ATN's common internetworking protocol. It may optionally be supported by the Inter-domain Routing Protocol (IDRP) over air/ground data links. The ICAO specification allows for both use of and non-use of IDRP and, its support may be left as a vendor/airline issue. IDRP could give benefits when users such as airlines and ATC providers make direct use of ATN services to communicate with aircraft.

The Connectionless Transport Protocol (CLTP) is proposed to support AOC traffic. This provides a per message checksum and an addressing capability on to which the existing message label can be mapped. However, some sort of convergence protocol is still needed to provide for message acknowledgement. Such a protocol would be partly the procedures for supporting ARINC 620 messaging using the service provided by the CLTP but is also expected to include a small additional header to support message acknowledgement in order to give an equivalent service level to ARINC 618.

This communications stack can support FANS-1/A using 622. Alternatively, the ATN connection mode transport protocol (TP4) and the ATN Dialogue Function could be made available to provide direct support of FANS-1/A - although this would require an FMS upgrade and, as such, is presented as a possibility rather than as part of the proposal. However, if such an upgrade took place, this would give much more reliable communications services and could, together with suitable operational procedures give rise to clear benefits for the airline user. Such a feature can be regarded as an option that vendors could make available.

4.2.2 Proposed Ground Architecture

Figure 4-4 illustrates the proposed Ground Architecture for a solution including ATN support.

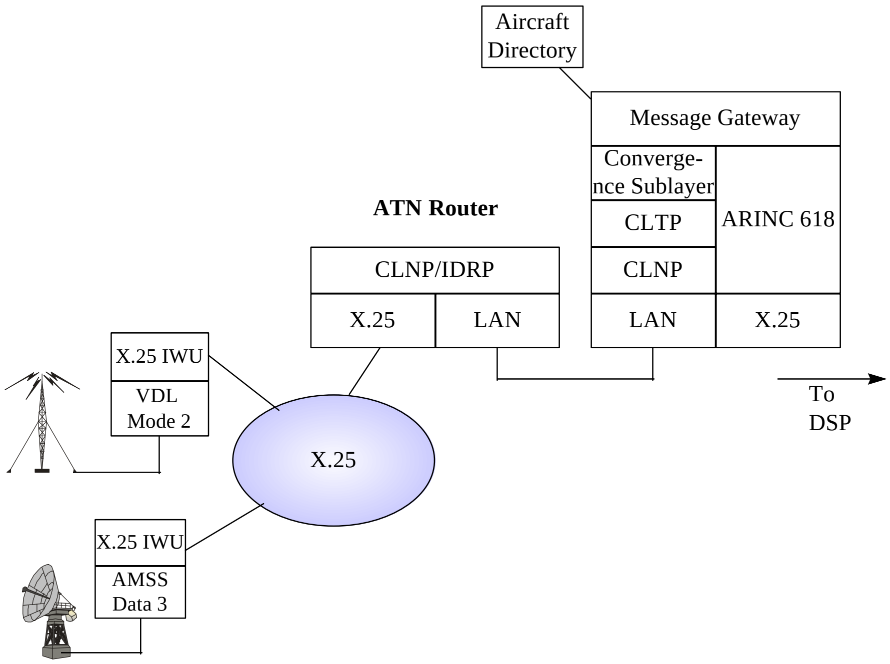

Figure 4-4 Proposed (ATN) Ground Architecture

The principal change to the ground architecture is the inclusion of an ATN Router. The expectation is that this is physically co-located with a Message Gateway (although that is not essential). The functionality required of this ATN Router is no different from that already demonstrated in the ADS Europe and ATIF Trials. It is therefore not regarded as a new development.

The Message Gateway no longer interacts directly with the X.25 network and is connected via the ATN Router - a LAN interconnect is shown here to emphasis physical co-location. The CLNP and CLTP protocol stack has also to be present, together with the convergence sublayer for mapping the ARINC 618 service to CLTP. Communication between the Message Gateway and the aircraft is by sending messages addressed to the aircraft's ICAO assigned ATN NSAP Address, and using the CLTP. The ATN is responsible for routing the resulting packet via the appropriate air/ground data link and could readily cope with one Message Gateway supporting several VDL and AMSS Ground stations.

A static directory could be used to relate aircraft registration marks to ATN NSAP Addresses. However, the relationship between Flight Numbers and NSAP Addresses is more dynamic and, as with the SITA proposal, some sort of message exchange may be necessary to support this function.

4.2.3 SVC Management

Air initiated SVC establishment is already assumed for both AMSS and VDL by the ATN. Therefore the SVC establishment procedures would be expected to be much the same as for the SITA proposal. The difference is that the DTE address chosen for the SVC's destination would be the well known DTE address of the ATN Router rather than the message gateway. Call establishment would follow the "Route Initiation" procedures specified in the ICAO SARPs.

Connection Termination has similar issues associated with it as with the SITA proposal. However, it is possible to site ATN Routers very close to VDL Ground Stations, whilst still having one Message Gateway for several Ground Stations (i.e. with a wide area link between router and Message Gateway). Essentially, this proposal offers more flexibility in tackling the issues here.

4.2.4 Multiple SVCs

There is no need for multiple SVCs between the aircraft and an individual VDL Mode 2 Ground Station. Service users (e.g. ATC providers) can interconnect with the ATN Router(s) which can handle them as well as the Message Gateway. Furthermore, ATN Routers for many Ground Stations can be interconnected as a preliminary to creating the global ATN.

4.2.5 Analysis

The proposed ATN functionality exists and has been demonstrated in trials The airborne software required is a subset of that already being developed for ATNSI. It is thus also a workable solution and, indeed many of the issues have been simplified. This includes the Routing Decisions on board an aircraft - which can rely on functions already developed for the ATN rather than having to develop new ones - and direct communications with ATC Providers and possibly airlines. Other network types may also be accommodated including LEOs and MEOs.

4.3 Conclusion

Two workable solutions have been proposed. However, the SITA proposal gives no transition path to CNS/ATM and the ATN except a replace all. Nor does it readily support direct connect to aircraft through (e.g.) VDL Mode 2 by ATC providers. On the other hand, introducing use of the ATN protocols into the SITA proposal removes both such problems. Furthermore, the additional functionality required has already been demonstrated in in-flight trials and there is a reduction in some of the new development required. There is also a tangible benefit for airlines due to the data compression service that can be offered leading to reduce traffic volumes and hence reduced costs.

The ATN based solution should thus give an immediate cost benefit without introducing any significant new cost drivers.

Furthermore, the continued (5% annual) increase in air movements will necessitate some form of movement towards CNS/ATM within the lifetime of the proposed equipment upgrade. As the only way this could be done with the SITA proposal is a replace all strategy, there is a clear risk that airlines would be forced to replace avionics based on this solution before the investment had been fully realised.

On the other hand, the ATN based solution gives two clear benefits. Firstly, it will enable extensive in-service testing of the concept to be undertaken before CNS/ATM services need to be introduced. This will help expedite their introduction and avoid the dis-benefits of late introduction. Secondly, transition will be much smoother as the ground network that supports full CNS/ATM can evolve gradually from that which supports AOC. Indeed, if the connection mode transport service is made available in support of FANS-1/A then the full potential of this product could be unlocked with early CNS/ATM benefits following in consequence.

There will still have to be an aircraft upgrade to move to full CNS/ATM even with an ATN based solution. However, that upgrade will be mostly in the FMS and in the FMS to CMU interface. The basic architecture of the CMU (as illustrated above) should not change.

5. Analysis of Development Requirements

From inspection of the above, it is possible to identify the main development items for proposal #2.

5.1 New Design

- **Message Gateway:** it will clearly be necessary to analyse the ARINC 620 SMIs and identify the message handling requirements of all messages. Many will be carried transparently through the gateway, while others will need to be interpreted. A Message Gateway Specification will need to be developed.

- **Convergence Protocol:** the existing ARINC 618 labels will need to be mapped on to CLTP TSAP-ids, and a procedure developed to ensure that the semantics of the existing ARINC 618 messages are preserved. This latter requirement is expected to require a simple protocol - most likely an encapsulation of ARINC 620 messages when they are sent over the CLTS. This convergence protocol will need to be specified.

- **Network Management:** dependent on the full analysis of the ARINC 620 SMIs, it may be necessary for there to be a network management dialogue between the Gateway and the VDL Ground Station e.g. to give meaningful reports on error conditions. This would be expected to use an existing network management protocol such as CMIP or SNMP over the ATN TP4 or CLTP respectively. A specification for such dialogues may need to be produced.

5.2 Software Development

The ATNSI Reference Router Implementation will be making available the ATN components and it is assumed that this product will be available and will additionally include support for the CLTP. The following additional developments are believed to be necessary:

- **VDL Mode 2 Airborne components**

- **Airborne Convergence Protocol and Routing Decision:** the software that will route outgoing ARINC 620 messages to either POA or the ATN stack needs to be developed, together with the convergence function that will convey ARINC 620 messages using the CLTP.

- **Message Gateway:** the message gateway function will need to be developed. It may be possible to use existing ARINC 620/618 software as the basis for the interface to the DSP. Portable OSI software already used for ATN prototypes may also be used for the ATN interface. The new development is believed to be primarily the address translation and message analysis functions, and the ground convergence function (the peer of the airborne convergence function). A Network Management interface may also have to be developed.

5.3 Integration and Portation

There are two major integration activities foreseen: the airborne systems and the Message Gateway. In addition, portation and integration of Ground ATN Router may be required to a platform other than the original development platform.

6. Transition Analysis

An important feature of proposal #2 is that it offers migration to the ATN. This section attempts to analyse how that migration might take place. A two phase process is foreseen, with each phase corresponding to an avionics upgrade. The first phase is primarily concerned with VDL Mode 2 introduction but also sees the progressive development of a ground ATN Internet, the gaining of considerable in-service experience of the management of such an internet, and ending with its certification/approval for support of CNS/ATM Applications.

The second phase requires an FMS upgrade to support the full CNS/ATM applications and replacement of the current FANS-1/A generation of applications. The airborne communications systems may not need to be upgraded. However, certification requirements may demand change. There may also be security and network management functions that are required as a result of the experience gained during phase 1. This may also demand an upgrade.

6.1 Phase 1 VDL Mode 2 Introduction

The justification for phase one starting is the need to gain increased capacity through an ACARS upgrade. Because of aircraft re-equipage timescales, it must also include the introduction of the ICAO ATN. Phase one concludes when a ground ATN Internet has been established, a critical mass of aircraft have been upgraded to VDL Mode 2, and end-to-end certification/approval of the ATN for support of CNS/ATM applications has been achieved.

On the ground, it is first assumed that VDL Mode 2 is introduced on a regional basis and as a package consisting of several Ground Stations, an ATN Router and a Message Gateway (as illustrated in Figure 6-1). Each such package looks like one or more legacy ACARS Ground Stations to the DSP. During this phase, the ATN Routers in adjacent regions may be interconnected in order to provide “direct” ATN services - especially to ATC providers. The same package approach may be applied to other A/G data links. Indeed, the Figure 6-1 configuration may include AMSS and HF Ground Stations as well.

On the airborne side, it is assumed that aircraft are also upgraded to support VDL Mode 2 with dual stack for “Plain Old ACARS”. They are thus capable of operating in either mode. Aircraft upgrade will take place over an extended period and, during this phase, there will be a decreasing number of aircraft with POA only support and an increasing number with POA and VDL Mode 2 support. Upgrade will start in the year 2000 and continue for several years thereafter.

Frequency management will be an issue during this period. VHF channels will gradually be taken from ACARS as the use made of ACARS decreases and VDL Mode 2 take-up increases.

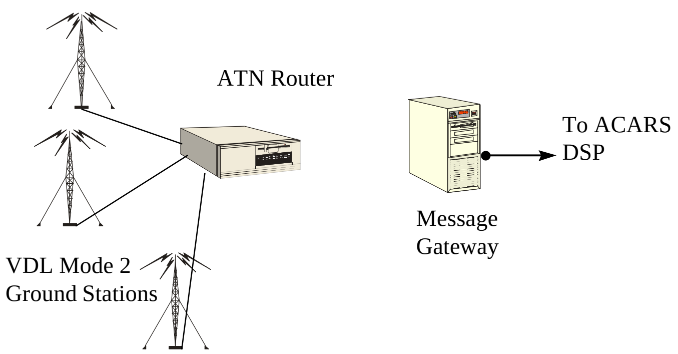

Figure 6-1 Proposed VDL Mode 2 "Package"

Although the above figure shows a package comprising one ATN Router and one Message Gateway, there is no reason why multiple ATN Routers could not interface many more Ground Stations to a single Message Gateway. This is essentially a deployment and capacity issue; ATN Routers are intended to be interconnected in order to build an internet and to provide for high reliability and availability through redundancy.

However, this may not be the only motivation for interconnecting the ATN Routers. ATC providers have already indicated that they wish to avoid the delays and risk of message loss introduced by having to send messages (e.g. to FANS-1/A) via a DSP. Interconnecting the ATN Routers in each and every deployment of VDL Mode 2 and providing access to the resulting ATN Internet to ATC providers, will support direct access to all VDL Mode 2 equipped aircraft flying in range of VDL Mode 2 (and similarly AMSS).

This will give the most value if the TP4 option (in proposal #2) is exercised for access to FANS-1/A equipped aircraft. The functionality of TP4 will give an immediate benefit in that it provides reliable end-to-end communications. There will also be the long term benefit of being able to gain long term in-service experience of the use of TP4/CLNP in an operational air/ground scenario. This is highly valuable for the progressing to full CNS/ATM and probably a pre-requisite for the certification/approval of the ATN for support of CNS/ATM.

For ATC, regional interconnect would be sufficient to realise many benefits. However, once global or near global interconnect has been achieved, then AOC users may also wish to make direct use of the ATN Internet for air/ground communications. The benefit of doing so will be shorter transit delays and end-to-end data integrity.

6.2 Phase 2 Introduction of CNS/ATM-1 Applications

The pre-requisite for this phase is the certification/approval of the ground ATN for support of CNS/ATM applications. The ground ATN will have been developed in support of VDL Mode 2, AOC use and FANS-1/A. It is now ready to support the next generation of CNS/ATM applications. The cost justification for this phase will come from ATC and other operational benefits accruing from CNS/ATM.

The phase 2 upgrade will be concentrated in the FMS and the ATC Centres, and comprises the implementation of the CNS/ATM applications. There may be no justification for upgrade of the airborne communications systems. However, the opportunity may be taken to remove the POA stack and, in its place, to include Network Management and Security features which are likely to be desirable in support of CNS/ATM. Other optimisations to the communications systems may have also become apparent during phase one, and this is the appropriate opportunity to bring these in as well.

Phase two concludes with the complete replacement of FANS-1/A equipment and the withdrawal of services based on this equipment.

7. ATN Benefits Analysis

Proposal #1 and proposal #2 have a common set of issues and risks associated with them. However, proposal #2 is believed to have a number of identifiable benefits associated with it that are not visible in proposal #1. This section analyses those benefits and any risks that might be incurred from an ATN solution.

7.1 Compression benefits

Data compression is perhaps the most tangible early benefit to be derived from ATN use. The ATN includes support for the negotiation of data compression algorithms and two of these are relevant to this application.

The first is the so called “LREF” algorithm. This was introduced to avoid the overhead of the CLNP header and its large addresses over an air/ground data link. It has been successfully used in ATN Trials and prototypes with no known issues associated with it. It should be regarded as an essential complement to CLNP over air/ground data links. The impact of the LREF algorithm is to reduce a CLNP header of approximately 60 bytes to 6 bytes.

The second algorithm is the “Deflate” data compression algorithm which is itself a combination of the LZ77 algorithm and Huffman Codes. It has only recently been introduced into the aeronautical environment but has already been extensively used by industry and popularised through its used in the well known “pkzip” utility. Owing to the extensive research performed on this algorithm and its wide-spread use, it is believed to be well suited to use in an aeronautical environment. Character mode AOC data is particularly suitable for compression with Deflate and, with the rapid convergence of the algorithm, compression ratios of better than 3 to 1 should be achieved. Analysis of ADS Europe trials data supports this view.

The main issue associated with the introduction of Deflate is the memory requirements of the algorithm. The amount required can be varied, but there is a trade off between memory utilisation and the compression ratio achievable. Between 170KB and 200KB per SVC is the amount of memory that should be budgeted for.

7.2 Use of Multiple Data Links

The ATN was always intended to make it straightforward to add new types of data links, and limits the impact of a new data link to the interface between it and CLNP. The benefits here include both air/ground and ground/ground data links.

In the air/ground case, there is interest in both HF data link and Low Earth Orbit Satellites. In the latter case, the access method may be B-ISDN rather than X.25. While the addition of support for such data links will require upgrade to airborne communications systems, there is nothing like the radical industry wide change that is having to take place with VDL Mode 2. The end user applications (e.g. ARINC 620) stay the same. Support for another subnetwork type is added below the CLNP layer, and a new Ground Station type gets added to the “cluster” in Figure 6-1. Those aircraft operators that can see benefits in the upgrade can implement it without affecting others.

On the ground, the ATN Internet is not restricted to X.25 everywhere (which appears to be a consequence of proposal #1), and the ATN Routers and their users can be interconnected by any suitable data link, including E1/T1, Frame Relay and B-ISDN. The choice of data link will be based on the technical requirements, availability and cost. The solution has the flexibility for the lowest cost data link to be chosen.

7.3 Clear transition plan

The proposed transition plan has already been outlined in section 6. A smooth transition to CNS/ATM is demonstrated. This is in addition to the smooth introduction of the new data links, including those not based on X.25. Proposal #1 is very much an X.25 solution with no clear transition to CNS/ATM.

7.4 Improvements to FANS-1/A efficiency and reliability

Proposal #2 also includes the possibility of providing reliable connection mode support to FANS-1/A. Although not strictly necessary to meet the AOC requirement, this will go a long way to removing the reliability issues associated with FANS-1/A and should enable improved ATC benefits interim to full CNS/ATM. In fact, such a phase is probably essential for the smooth introduction to CNS/ATM.

This is because in order to introduce CNS/ATM and to achieve ATC benefits such as reduced pilot and controller workload, the ATN Internet will have to be certified/approved for support of such applications, as there are safety implications from realising such benefits. In turn, this will require an extended period of in-flight testing preferably in operational circumstances, with the intention of demonstrating that the ATN Internet can provide, to the satisfaction of the regulator, reliable end-to-end operation.

The deployment of the ATN Internet providing FANS-1/A with reliable connection mode services provides the opportunity to provide an extended period of in-service testing whilst realising some interim benefits. Support of this mode of working from the beginning of phase one is highly desirable. However, it can also be introduced later during phase one without affecting the aircraft that were upgraded first.

7.5 Risk Assessment

While there are clear additional benefits from an ATN related approach, the question will arise as to where are the additional risks. This section attempts to answer such questions.

Firstly, it should be noted that the ATN functionality required is no more than that already demonstrated in trials such as ADS Europe. There is thus not believed to be any functional risk. However, the software in the ADS Europe trial did not have to be certified and was not certified. ATNSI is having certified ATN software developed and the developers do believe that they can complete the development in the timescale. However, the main risk is believed to be availability of certified ATN code. This can be broken down by subsystem noting the degree of risk.

	SubSystem	Certification Risk	Notes
1.	Mobile SNDCF	Medium	Deflate algorithm will need to be analysed as part of the certification. However, as data is protected by an independent checksum, this may be a non-issue.
2.	CLNP	Low	CLNP is a simple datagram format. Routing decision is limited to a simple choice between the alternative datalinks
3.	IDRP	High	IDRP is a powerful rule based routing protocol and may prove difficult to certify for airborne use without a pre-operational trial.

4.	CLTP	Low	CLTP is a simple datagram format. Checksum algorithm will need to be verified but this has already been done by third parties.
5.	TP4	Medium	TP4 is a finite state machine based connection mode protocol. No major issues are foreseen in its certification. However, because of its central role in maintaining end-to-end communications, it may be subject to rigorous examination.
6.	ATN Upper Layers	Low	Functionality is limited.
7.	Application ASEs	High	A large number of message formats to be examined and an ASN.1 compiler to validate.

In terms of risk mitigation, there are clear advantages in leaving IDRP and the Application ASEs out of the airborne phase one package.

The primary use of IDRP in the ATN is for ground-ground routing in support of mobile systems. This role is not compromised by not using IDRP over the air/ground data link. Indeed, the ATN SARPs make use over the air/ground data link an optional feature and in this proposal, it is recommended that this certification risk is mitigated by not including IDRP in the airborne package. However, IDRP will certainly be necessary for support of ATN Router interconnection on the ground and part of the in-service experience gained during phase one will be the extensive use of IDRP on the ground.

The Application ASE are not required in proposal #2, even for FANS-1/A support. However, they are part of the ATNSI deliverable and will eventually be needed for full CNS/ATM. They can thus be included/excluded at the discretion of the supplier.

8. Conclusion

The need to replace the current ACARS system represents an almost perfectly timed opportunity to start the transition to CNS/ATM. The cost of re-equipage is largely justified in respect of the AOC requirement for increased VHF data capacity, but, by using this as a vehicle for the introduction of the ATN, there is a chance to both bring forward the introduction of CNS/ATM and the benefits it will bring and to minimise the airline equipage cost as well.

Including ATN functionality in this upgrade seems to add nothing to the complexity and risk. Indeed, it may simplify certain issues such as address management, and provide significant improvements to FANS-1/A. Multiple data links are readily accommodated

Apart from the services provided to the End User, a ground ATN Internet will enable in-service operational experience in the ATN to be obtained. This is almost certainly a pre-requisite for the certification/approval of the ground ATN Internet in support of CNS/ATM and, at some time, this exercise will have to be performed.

By combining the introduction of the ATN with the VDL Mode 2 upgrade, introduction of CNS/ATM will be expedited without any further costs other than the necessary upgrade of the FMS to support CNS/ATM. Proposal #2 meets the requirements, has been validated and is therefore considered to be low risk.