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Proposed Ground Network Design for the EuroVDL Project

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SUMMARY

This paper was prepared in the context of the EuroVDL project and comprises both analysis of the VDL Mode 2 subnetwork and a proposed architecture for the Ground Network supporting the EuroVDL project. This ground architecture is still under discussion and is not yet finalised. It is provided to WG2 in support of the discussion concerning the need for a “Handoff Event” to complement the existing Join and Leave Events.

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1. Introduction

1.1 Background

The EATCHIP Task Force COM.ET2.ST15 has identified VDL Mode 2 as a likely Air/Ground Data Link for ATN use. However, experience needs to be gained in the operational use of the service, the Quality of Service that can be expected, and so on. In order to achieve this, a pilot implementation is being planned, using commercial aircraft. This is the EURO VDL Mode 2 project, which is financed by the CEC (TENs - DGVII), Eurocontrol and the project partners (ENA, NATS, SITA, STNA). The Project aims to define and validate all the elements required for the implementation of a VDL Mode 2 Air/Ground datalink subnetwork as part of the ATN.

To fulfil this objective, the Project will:

- identify, define and develop as needed the elements and methods required for implementing such a network;
- validate them through a pilot VDL Mode 2 sub network of the ATN internet, supporting all the current AOC applications of the associate Airlines and one ATN compliant ATS service to aircraft on operational flights.

In order to achieve this, aircraft will be equipped with VDL Mode 2 radios and communications units, a network of VDL Mode 2 Ground Stations will be deployed, and linked by a Ground Network, including ATN Routers and End Systems. A trial application - ADS - has been selected for the purposes of demonstrating the use of VDL Mode 2 for CNS/ATM, and Airline Operational Communications (AOC) will also be supported using the AEEC specification for supporting ACARS over VDL Mode 2, and the ATN.

It is intended that the EuroVDL network will provide an open architecture to permit the evaluation of a simple configuration to start with, but be able to evolve to more optimal network operation and management strategies.

Note: Although the PETAL II project extension also requires a VDL Mode 2 infrastructure, EUROVDL and PETAL II are deliberately kept separate in terms of ATN and Subnetwork Network Design. The two projects have different applications, partners and VDL Mode 2 service providers. Section 4 below is EUROVDL specific (it is not applicable to PETAL II) while Section 3 addresses generic design principles and is generally applicable.

1.2 Scope

This paper analyses the possible operation of the EuroVDL network and proposes a network design for the Ground Network. It will be a precursor to papers on the specification and proposed operation of the network.

1.3 Purpose of Document

This paper has been prepared for the EuroVDL project and for discussion within the project. It may then be developed into the actual network design specification.

2. Summary

VDL Mode 2 is an ICAO specified air/ground data link. However, like all ICAO specifications, its scope is restricted to air/ground communications and the interconnections between States. The VDL SARPs only discuss the former, and the supporting Ground Network and the use of important mechanisms, such as Handoff, are absent from the SARPs.

This paper is concerned with proposing the architecture of the Ground Network supporting the EuroVDL project. In order to do so, it starts by analysing the VDL SARPs in order to identify the key facilities and issues for VDL Mode 2 implementation, and thus the options for the supporting Ground Network. Several candidate network architectures are investigated and it is concluded that the optimal architecture is one where there is a tight integration between the supporting Ground Network and the ATN. The optimal end state Ground Network architecture comprises a network of Level 2 IS-IS Routers and full ATN Routers (BISs) organised as a single Routing Domain. The service provided by the network to end users is the ATN's connectionless network service. The primary justification for this proposed architecture is that it both minimises the air/ground protocol overhead and optimises the Ground Network performance.

Although the air/ground VDL Mode 2 service is specified as an X.25 virtual circuit service, it is not proposed to make this available as an end-to-end service - although neither is this precluded if such a service was desired. The reason for not basing the Ground Network on X.25, is that the virtual circuit service available under VDL Mode 2 is one that is subject to regular disruption. Every time an aircraft changes Ground Station, the old virtual circuits are cleared and new ones established. As discussed in 3.4.3.5, there are ways to make it appear to a ground user that the circuit has not changed. However, this can probably not be done without generating a "Network Reset" on every Handoff and will result in network sizing and performance problems due to packets potentially crossing the same network many times. This problem can only be avoided by including what is believed to be "special to type" functionality in an X.25 network, and this is not believed to be justifiable.

A move away from X.25 is also believed to be desirable in the longer term, as X.25 is old technology and it does not really make much sense to predicate a new network service on it. Using ATN Routers means that existing X.25 ground networks can be used to provide the data links to begin with, and then later replaced with (e.g.) Frame Relay and ATM as and when required, without affecting end users.

An integrated ATN solution makes sense as it is the service to be provided to end users, and the ATN Routers will hide the disruption of service on Handoff, from end users. Using a combination of Level 2 IS-IS Routers allows the optimal path through the Ground Network to be maintained as an aircraft moves between Ground Stations, whilst avoiding any air/ground IDRP traffic on Handoff. This is why it is optimal for both ground and air/ground.

However, the EuroVDL project is only concerned with the initial deployment of VDL Mode 2 and, while such a goal architecture may be considered in an extension to the project, the architecture of the VDL Mode 2 network implemented for EuroVDL will be more limited and hence less optimal.

The primary objective of the EuroVDL project is the early availability of a VDL Mode 2 service to a limited number of trials aircraft; there should be the minimum amount of new development needed to achieve this.

As a result, the proposed EuroVDL architecture comprises the initial set of Ground Stations with an ATN Router (a BIS) associated with each group of Ground Stations. The BISs are linked to form a single Routing Domain, and may interconnect with other ATN Routing Domains. Only Air-initiated Handoffs are supported with no co-ordinated ground operation of the network. EuroVDL will, as proposed provide a VDL Mode 2 service on a single

frequency, but there will be no attempt to manage aircraft use of the service, and IDRP routing information will be exchanged on every Handoff.

Later on, this initial implementation may evolve into the Goal Architecture. The first step in this will be the re-configuration of the EuroVDL Routers into Level 2 IS-IS Routers and the deployment of two “central” ATN Routers (BISs). This will be used to eliminate the exchange of IDRP Routing Information on Handoff, as described in 3.4.3.6.

Following on from this will be the development of a Network Management Centre (NMC). This will enable the co-ordinated management of the network and, most importantly, the active management of aircraft use of Ground Stations in areas of overlapping coverage in order to optimise demand to available capacity. The NMC will enable to introduction of Ground Initiated and Ground Requested Handoffs in a co-ordinated fashion. The NMC will also facilitate the introduction of VDL Mode 2 service on additional frequencies.

Following on from this paper, there is a significant amount of further specification needed. This is discussed in the conclusion to this paper.

3. VDL Mode 2 Analysis

3.1 Overview

The VHF Digital Link (VDL) Mode 2 is an ICAO specified air/ground communications data network using 25KHz channels in the Aeronautical VHF band. It is an evolutionary development of the existing ACARS communications service, that has been serving commercial airlines for over twenty years, with an evolution that extends through its precursor - VDL Mode 1.

ACARS itself is a character mode communications service using modems that provide a 300 baud modulation rate in a 25KHz channel. Carrier Sense Multiple Access (CSMA) procedures being used to permit multiple users to access the same channel and to arbitrate channel access between them. VDL Mode 1 improves upon existing ACARS by replacing the character mode protocols with a binary data communications protocol closely related to ITU-T recommendation X.25, while using the same modulation rate and CSMA procedures. VDL Mode 2 is as Mode 1, but uses an improved modulation algorithm. This is the D8PSK (Differentially encoded 8-Phase Shift Keying) algorithm, which permits a bit rate of 31.5 Kbps in a 25Khz channel. While the commercial justification for replacing ACARS with Mode 1 is unclear, the substantial gain in throughput with D8PSK makes VDL Mode 2 much more attractive than either ACARS or VDL Mode 1. With ACARS capacity now almost exhausted, there is a clear justification for the replacement of ACARS with Airline Operational Communications (AOC) based on VDL Mode 2, and this is expected to occur by 2001.

The ICAO SARPs only specify the air/ground data link procedures and protocols for VDL Mode 2. However, the SARPs also provide support in the air/ground protocols for the co-ordinated operation of the Ground Stations, and there is an implicit assumption that VDL Mode 2 Ground Stations will be grouped together and operated by a single Service Provider. The SARPS do not prevent multiple Service Providers operating networks that have overlapping areas of coverage, not do they prevent aircraft from moving between Service Providers. However, the support is provided for co-ordinated operation of many Ground Stations, operating over different frequencies and with both different and overlapping coverage areas. The purpose of such co-ordination is to permit the most efficient use of available bandwidth over one or more channels.

The ICAO SARPs do not specify how VDL Mode 2 Ground Stations are linked to each other or to ground users. However, Figure 3-1 can be assumed to be a generic architecture for a VDL Mode 2 network operated by a single Service Provider or State.

In concept, a VDL Mode 2 network may consist of a number of Ground Stations, linked to each other and to Ground Users by some supporting Ground Network infrastructure. The Air/Ground protocol is derived from ITU-T X.25, and it may be supposed that the ground network is also an X.25 network. However, that is not a requirement and other networks could be used to provide the service. Indeed, when considering the ground network architecture, an important limitation in the use of X.25 for air/ground communications needs to be considered, that is SVCs may only be air-initiated. Ground Users can only be contacted by an aircraft, they cannot contact an aircraft.

This limitation avoids having to provide any support for mobile routing within the VDL Mode 2 network. ICAO has also specified the Aeronautical Telecommunications Network (ATN) which does provide support for mobile routing and the expectation is that VDL Mode 2 is used in conjunction with the ATN. An aircraft needs only to contact a suitable ATN Router through the VDL Mode 2 network, and it can then communicate with any other user of the ATN, with no restriction on who initiates a subsequent message exchange.

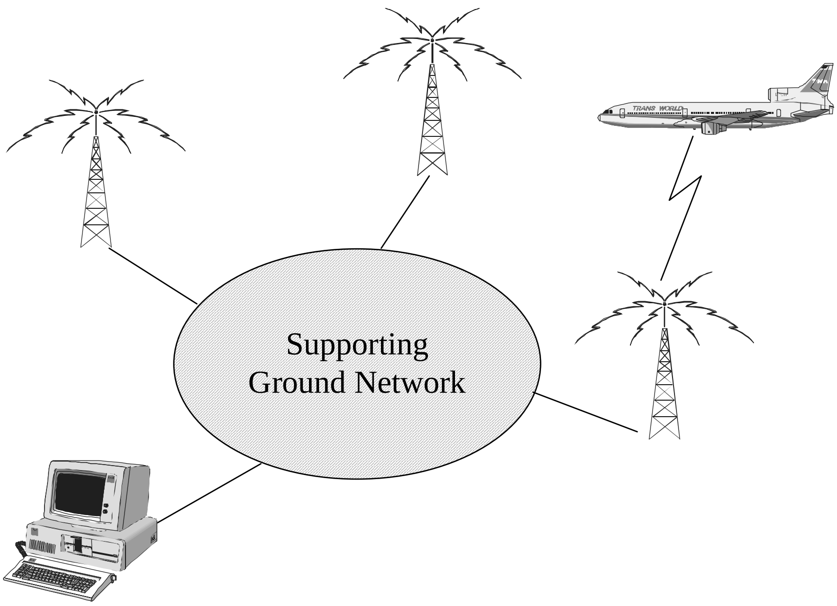

Figure 3-1 VDL Network Concept

Similarly, in a simple upgrade of the ACARS environment, an aircraft would only have to contact the Service Provider’s Data Services Processor (DSP), in order to receive ACARS service and for airlines to be able to send messages to their aircraft.

However, this is not the only reason for the ground network being more than just X.25, as aircraft tracking is also an issue. An aircraft will initially logon to the VDL Mode 2 network via a specific Ground Station, and establish one or more SVCs through that Ground Station. As it continues on its flight, it may request “Handoff” to another Ground Station (before it goes out of range of the first one), or the VDL Mode 2 Network Manager may instruct the aircraft to change to a different Ground Station, either on the same or a different frequency. This will be for reasons to do with optimising the use of available Ground Stations and channels.

Everytime that “Handoff” occurs, the virtual circuits have to be re-established. This is expedited on the air/ground side by using one message to perform the Handoff and virtual circuit establishment. However, this still means that the existing virtual circuits in the ground network must be cleared and new ones, through the new VDL Ground Station must be established. This has a potentially significant impact on both the ground network and the end-to-end communications, as in VDL Mode 2, virtual circuits between an aircraft and ground user will typically be short lived (essentially the period during which an aircraft is in a given Ground Station's coverage - or less when congestion forces rapid change between Ground Stations). If the virtual circuits were being used to support an end-to-end application, then that application would have to cope with the ensuing disruption. Furthermore, the ground network will have to cope with a relatively high rate of virtual circuit clearing and establishment.

Again, using VDL mode 2 via the ATN hides the changes in virtual circuits from end-to-end communications. Furthermore, there is also an argument for distributing ATN Routers within the VDL subnetwork, as this will localise the impact of virtual circuit changes, giving a more rapid response to change and reducing the total network load of virtual circuit change.

The VDL Mode 2 ground infrastructure should thus not be thought of a subnetwork independent of the ATN. The most likely architecture involves a close integration of the two, such that a VDL Mode 2 Network is also an ATN Routing Domain, and the users do not see a network distinct from the ATN.

3.2 Protocol Architecture

The protocol architecture for VDL Mode 2 is illustrated alongside in Figure 3-2. At the physical layer, the D8PSK modulation scheme is specified. The Data Link Layer is then split into a Media Access (MAC) sublayer, and a Logical Link Control layer. The former implements the CSMA media access procedures, with the later using HDLC framing and protocol procedures for a connection mode data link. The packet layer follows ITU-T X.25 and provides virtual circuit oriented communications.

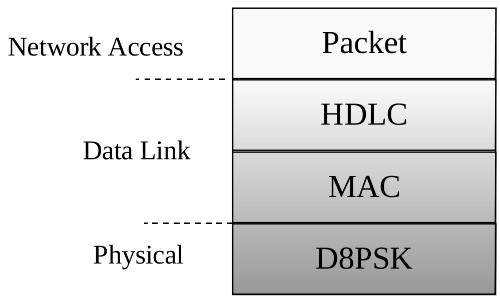

Figure 3-2 VDL Mode 2 Protocol Architecture

The ICAO SARPs also specify two Management entities: the VDL Management Entity (VME), that manages the service as a whole, and the Link Management Entity (LME) that manages communications with a single peer system. For example, an aircraft has an LME for each Service Provider with which it is in contact and, similarly, a Service Provider has an LME for each aircraft it is in communication with. This architectural model ensures that an aircraft does not have multiple concurrent relationships with the same Service Provider.

The physical layer is outside of the scope of this paper. However, it is useful to analyse further the MAC, logical link control and packet layers.

3.2.1 The VDL MAC Sublayer

The VDL MAC Sublayer specifies the framing for all packets transmitted over the VHF data link and the channel access procedures. All packets are broadcast over the channel using p-persistent CSMA. In order to transmit a packet, the transmitter will first listen to the channel and only if the channel is quiet will the transmitter send the packet. In fact, it may not even transmit then. The probability (p) that it will transmit defaults in VDL Mode 2 to 13/256. If it does not transmit then the transmitter will wait a short period (typically 4.5ms) before trying again, and will make up to 135 attempts to transmit a single packet before giving up. The channel will also be declared congested if a transmitter has been unable to send a packet for 60 seconds from having first tried and failed to send one.

Packets are broadcast and are received by all stations in range. Each packet has both a source and destination address so that a receiver will only receive those packets addressed to it.

An eight octet address structure is specified for VDL Mode 2, with the address space structured into separate addressing domains for Aircraft and Ground Stations. Aircraft use their 24-bit ICAO Address, and Ground Stations are assigned unique addresses from either an ICAO Administered Address Space (delegated to States) or from one delegated to a service provider. Broadcast and multicast (e.g. all Ground Stations) addresses are also specified.

3.2.2 VDL Logical Link Control

The Logical Link Control sublayer implements an ISO 3309 (HDLC) subset to provide for connection mode communications over the VDL MAC sublayer. The following HDLC frames are specified for VDL Mode 2:

- INFO [Information]
- RR [Receive Ready]
- XID [Exchange Identity]
- TEST
- SREJ [Selective Reject]
- FRMR [Frame Reject]
- UI [Unnumbered INFO]
- DISC [Disconnect]
- UA [Unnumbered Acknowledge]
- DM [Disconnected mode]

In general, the use of HDLC follows normal practice and the ISO specification. However, the XID format becomes an important and multi-purpose frame in VDL. The XID frame is used for both the initial logon to a VDL Mode 2 network and for Handoff. It can convey information on an aircraft's location and the airports covered by a given Ground Stations. An aircraft can use it to report a Ground Station's signal strength, and a Ground Station can use it to tell an aircraft about alternative Ground Stations. It can also be used to convey packet level CALL REQUEST and CALL CONFIRM packets in order to expedite the call establishment process, especially on Handoff.

It should be noted that many of the VDL specific parameters of the XID are optional, and their use can depend upon the requirements of the Service Provider. In turn, the procedures of use can be Service Provider specific. It follows that a VDL Service must provide a VDL Subnetwork profile for the use of the service that is in addition to the SARPs.

3.2.3 The VDL Packet Layer

The VDL Packet Layer is an implement of ITU-T X.25 as specified in ISO 8208. It includes a number of optional facilities, including Fast Select (used by the ATN to optimise the Route Initiation procedure). The implementation of ISO 8208 is asymmetric, with the Ground Station taking on the role of the DCE with the aircraft as the DTE. Only aircraft can initiate virtual circuits.

Addressing is also asymmetric. The aircraft's DTE Address is the BCD representation of the aircraft's ICAO 24-bit address, while two modes of ground DTE Address are provided for.

The first mode is for addressing ATN Routers. The NETs of nearby ATN Routers are passed to an aircraft in a Ground Station's XID, and the ADM and (optionally) ARS fields of the NET are conventionally used as the destination address for a Call Request by leaving the Called Address field empty and by BCD encoding the ADM (and ARS) as the Called Address Extension. If the Ground Station is directly connected to the ATN Router then it can readily pass on this Call Request to the ATN Router. If it is not, then it must map the Call Request to the ground DTE Address of the ATN Router and pass on the Call Request to that DTE Address. The functionality required here is similar to the X.25 Interworking Unit described in ISO TR 100029.

The second addressing mode is optional and may only be used when the capability is advertised by the Ground Station. In this mode, the aircraft is permitted to use a valid X.121 address as the Called DTE Address and the Ground Station will pass on the call to that X.121 address. The aircraft must have *a priori* knowledge of this X.121 address.

3.3 Operational Procedures

3.3.1 Network Logon

Aircraft that are currently without VDL service are expected to scan known frequencies for ground stations providing a suitable VDL service. A Common Signalling Channel (CSC) is defined for this purpose on 136.975 MHz, and all Ground Stations are required to announce their service on this channel and any others that they use. Apart from the CSC, Aircraft have to know in advance of any other channels to scan.

Ground Stations periodically announce their service by transmitting a broadcast XID to all aircraft. This is known as the “Ground Station Identification Frame” (GSIF) and provides information on the facilities supported, ATN Routers available through the Ground Station, airports covered and may also identify the frequencies supported. Through the source address of the GSIF, the aircraft may also identify the State or Service Provider. Aircraft choose Ground Stations on a mixture of signal quality and contractual considerations.

In order to logon to a Ground Station, the aircraft uses another XID variant defined by the SARPs. This XID is known as the XID_CMD_LE and is sent (formally by the Aircraft’s LME) to the Ground Station to request link establishment. The link establishment is accepted (or rejected) by the Ground Station sending back an XID_RSP_LE frame to the aircraft.

Once the link is established, the VDL SARPs identify two different procedures for initiating communications over VDL. These are the *Explicit Subnetwork Connection Initiation* and the *Expedited Subnetwork Connection Initiation*.

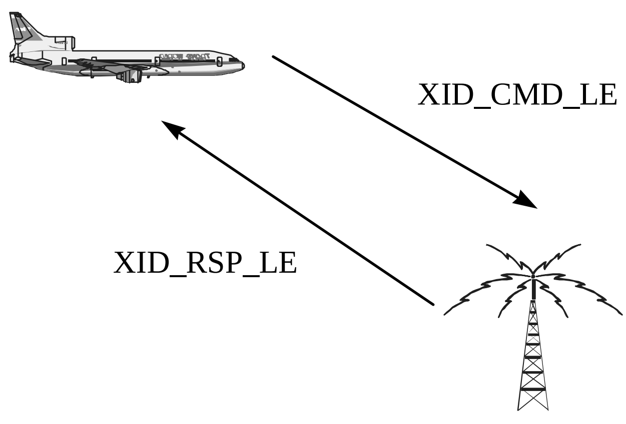

Figure 3-3 Message Exchange for VDL Data Link Initiation

3.3.1.1 Explicit Subnetwork Connection Initiation

Under Explicit Subnetwork Connection Initiation, the establishment of virtual circuits across the VDL subnetwork is performed separately from the data link initiation, as illustrated in Figure 3-4.

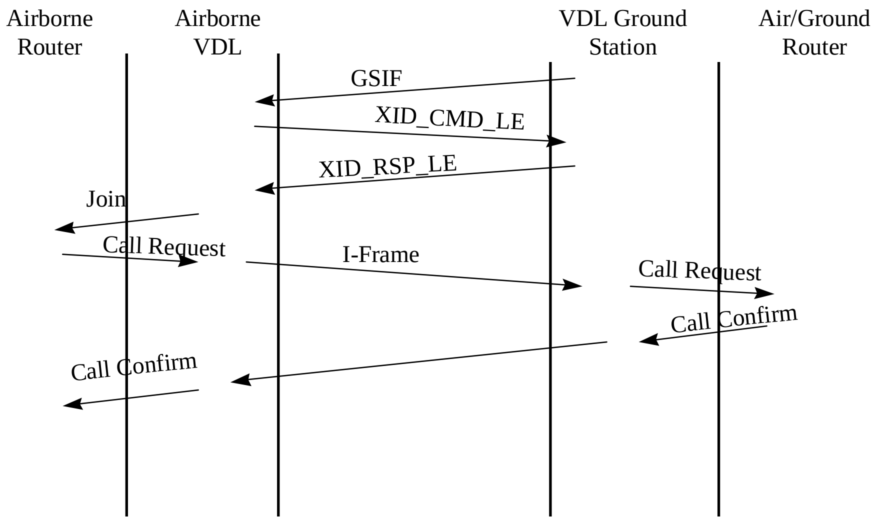

Figure 3-4 Explicit Subnetwork Connection Establishment

As described above, once a GSIF has been received, the XID_COM_LE and the XID_RSP_LE frames are exchanged. Once an XID_RSP_LE has been received from the Ground Station confirming that the data link is established, a Join Event can be sent to the router reporting the NETs of the ATN Air/Ground Routers available through the Ground Station.

The response to the Join event will be as described in the ATN Internet SARPs for air initiated data links: the Join event is received by the IS-SME, which generates a Call Request addressed to once of the ATN Routers, with the ISH PDU encapsulated in the Call Request User Data. This is transported over the VDL data link in an Information (I) frame, received by the addressed Air/ground Router, which should then respond with a Call Confirm, and so on until the Route Initiation procedures are complete, as described in the ATN Internet SARPs.

3.3.1.2 Expedited Subnetwork Connection Initiation

The *Expedited Subnetwork Connection Initiation* procedures are designed to optimise bandwidth utilisation by combining virtual circuit establishment with data link initiation, and are illustrated in Figure 3-5.

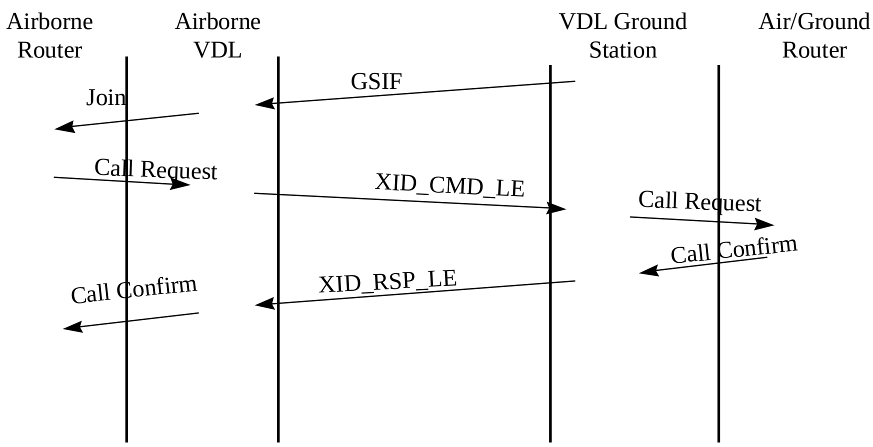

Figure 3-5 Expedited Subnetwork Connection Establishment

Under these procedures, the Join event is generated as soon as a GSIF is received, but without a preceding data link initiation. The IS-SME will still handle the event as described in the SARPs and generate a Call Request. However, this Call Request may be buffered by the VDL subnetwork before it is despatched as part of the data link initiation.

With *Expedited Subnetwork Connection Initiation,* an XID_CMD_LE can contain several Call Requests. A VDL subnetwork, even on board an aircraft, may have several users each receiving a Join event and it should give each user a change to process the Join event and respond with one or more Call Requests before proceeding with data link initiation. The VDL subnetwork may thus wait until some timer has expired, before continuing. Alternatively, a local interface may be specified with some explicit “Join Event Processing Complete” message that is sent from the VDL user to the VDL subnetwork. Data Link Initiation may then commence as soon as all users that received the Join event have responded with “Join Event Processing Complete”.

The XID_CMD_LE is then sent with the Call Request(s) contained within the frame. This is received by the Ground Station, which extracts the Call Request(s) and delivers them to their address destination. It will then wait for the responding Call Confirms or Rejects to be received before including them in the XID_RSP_LE uplinked to the aircraft in response.

Similarly, the aircraft VDL software will extract the Call Confirms/Rejects and pass them to the address local users. Route Initiation will then proceed as described in the SARPs.

3.3.2 Handoff

Handoff is the general term for an aircraft changing its point of attachment from one Ground Station to another. This may be initiated by an aircraft or by the operator of the VDL network.

3.3.2.1 Air-Initiated Handoff

In a light to moderately loaded VDL network, air-initiated Handoff should be the norm. Each aircraft is expected to monitor the signal strength/quality of the Ground Station(s) to which it has established a data link and may also monitor the signal quality of others in the same region. When the signal quality goes below an acceptable level, or indeed, when there is a communications failure with the Ground Station, the aircraft is expected to choose a new Ground Station. It sends an XID_CMD_HO message to the chosen new Ground Station in order to request the Handoff and, if this is acceptable to the new Ground Station, it responds with a XID_RSP_HO message. It can also reject the proposed Handoff with a XID_RSP_LCR message. When a Handoff has been accepted, the aircraft terminates the old data link either:

a) by transmitting a DISC frame, perhaps after waiting for a short time to ensure that all data has been transferred over the old data link. This procedure is performed when Handoff occurs between Service Providers; or,

b) by both avionics and the old Ground Station starting a timer and automatically clearing the calls at timer expiry. This procedure is used when Handoff occurs between Ground Stations belonging to the same Service Provider, and implies that some sort of message is sent between new and old Ground Stations.

The XID_CMD_HO, etc. are all XID variants and, as with the XID_CMD_LE and XID_RSP_LE, CALL REQUESTs can be expedited by including them in the XID frame. However, this is not a mechanism for transferring a virtual call as such. A VDL Virtual Circuit is only valid in the context of a single data link and, when the Ground Station changes, new virtual circuits have to be established.

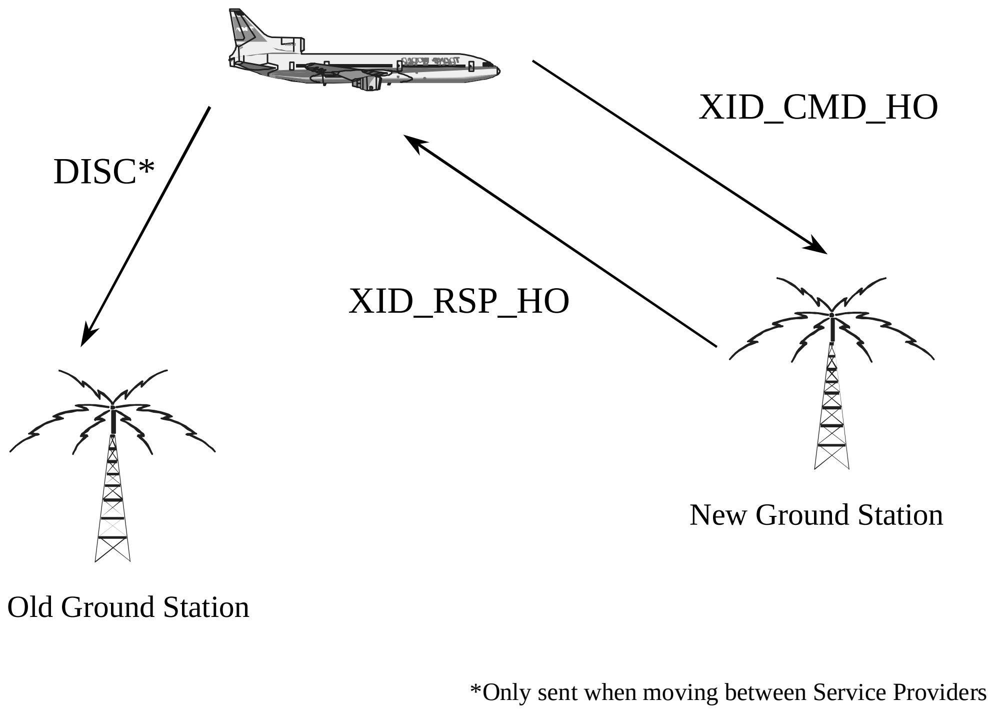

Figure 3-6 Air-initiated Handoff

The intention is that on Handoff, an aircraft will identify the virtual circuits it currently has through the current Ground Station and initiate new virtual circuits (if possible) to the same destinations through the new Ground Station. The old virtual circuits are then terminated. It is theoretically possible when Handoff occurs between Ground Stations under the same point of control, for the Ground Network to try and match the new air/ground virtual circuits to the original ground path and thereby to avoid establishing a new virtual circuit all the way through to the Ground DTE. However, packet sequencing cannot be guaranteed during Handoff, and the ground portion of the virtual circuit would, in such cases, have to be reset. There would still be the same end-to-end disruption of service.

Ground Stations do advertise the ATN Routers they serve in their GSIF, and the aircraft should try and avoid changing ATN Router when choosing a new Ground Station. Moreover, the new virtual circuit is recognised by the ATN Router as being related to the old and the data compression context is carried over. This is an important feature in minimising the overheads of Handoff.

If there is no suitable Ground Station providing service to the current ATN Router, then Handoff to a new Ground Station also includes contact with a new ATN Router, and the ATN's mobile routing capabilities are relied on to maintain end-to-end service.

It is also important for the old Ground Station to react rapidly to the DISC frame or timer expiry by clearing the existing virtual circuits. This is desirable when the aircraft maintains communication with the same ATN Router as it frees up resources that would otherwise be unused. It is essential when the aircraft moves to another ATN Router, as the virtual circuit clear indication at the ATN Router generates the "Leave Event" that initiates the rapid change in the ATN's routing information and which ensures seamless transition from one ATN Router to another.

As with network logon, there are two mechanisms specified in the VDL SARPs for maintaining the virtual circuits. These are *explicit subnetwork connection maintenance* and *expedited subnetwork connection maintenance.*

3.3.2.2 Air Initiated Handoff with explicit subnetwork connection maintenance

Under the "explicit subnetwork connection maintenance" procedures defined in the VDL SARPs, the Handoff event follows the successful exchange of XID frames and comes before the DISC frame is sent to the old ground station or the old virtual circuits timed out. The receiver of the Handoff event responds to it by initiating new virtual circuits to the DTE Addresses identified on the Handoff event and directing them via the appropriate Ground Station, according to local procedures. This is illustrated in Figure 3-7 for air initiated Handoffs.

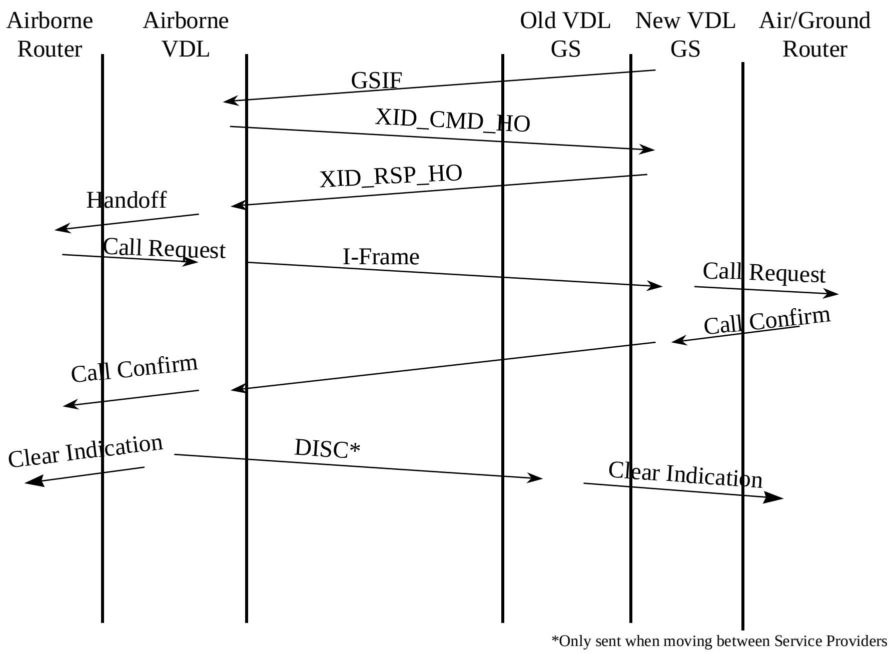

Figure 3-7 Explicit Subnetwork Connection Maintenance (Air Initiated Handoff)

When Handoff is between Service Providers, there is an issue over co-ordination of the sending of the DISC frame with the successful completion of the Handoff. Starting a timer from the exchange of XIDs and sending the DISC after the timer has elapsed will probably be the best strategy. This has to happen anyway in order to avoid various error conditions and avoids having to have additional interactions. Keeping the datalink with the old Ground Station open for longer than necessary should not cause a serious problem as all data will be routed over the new datalink as soon as it is available and, keeping the old one open for a reasonable period also ensures that data in transit when the Handoff occurred is not lost due to the datalink being cleared down too quickly.

3.3.3 Handoff with expedited subnetwork connection maintenance

With the expedited procedures, the sending of the Handoff event to the subnetwork user must precede the XID exchange. However, the response to the event is the same, that is the subnetwork user will issue Call Requests to the identified DTE addresses and direct them via the identified Ground Station. There will at this time be no data link between the aircraft and that Ground Station. As with expedited subnetwork connection initiation, the Call Requests will therefore have to be buffered by the subnetwork until either all DTE Addresses identified in the Handoff event have Call Requests buffered up or a timer has expired. The XID exchange can then take place, with the Call Requests sent on the XID_CMD_HO.

Before an XID_RSP_HO can be returned, the Call Requests must be forwarded to the identified DTEs and Call Confirms returned and similarly buffered until either all expected Call Confirms have been received or, again, a timer expires. The XID_RSP_HO can then be returned, including the Call Confirms, which are then passed to the initiating DTEs.

As the new virtual circuits are in place as soon as the XID exchange has been completed, the DISC can be sent to the old Ground Station soon after the XIDs have been exchanged, or the virtual circuits timed out when Handoff does not change Service Provider.

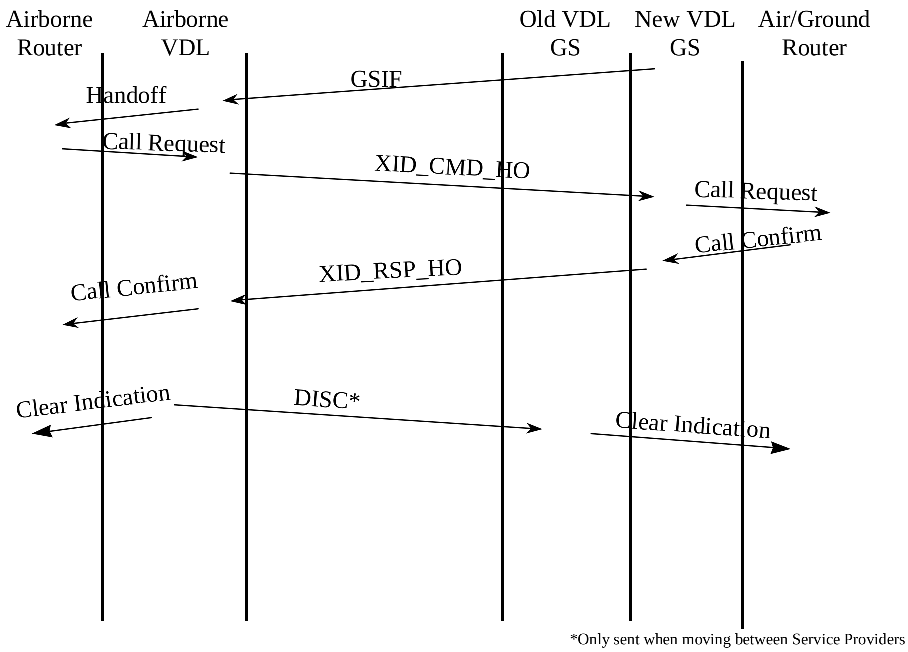

Figure 3-8 Expedited Subnetwork Connection Maintenance (Air Initiated Handoff)

3.3.3.1 Ground Initiated Handoff

In a moderate to heavily loaded network, the Service Provider will need to actively manage the Ground Stations used by each aircraft. For example, an area may be served by multiple co-sited Ground Stations on different frequencies. For purely statistical reasons, one Ground Station may be serving a high number of aircraft and throughput is suffering as a result, while another is serving only a few aircraft. In order to balance the load on the network, the Service Provider will need to select a number of aircraft on the heavily loaded Ground Station and move them to the less loaded Ground Station. Alternatively, they may be moved out to a geographically separate Ground Station before the aircraft itself initiated the change.

The choice of aircraft is important. There is, for example, little value in moving an aircraft that is about to move out of coverage anyway, to a Ground Station on the same site but at a different frequency. However, there is value in perhaps forcing such an aircraft to move to another Ground Station before it would have done so itself.

The measurement of the signal strength of an aircraft transmissions is probably the primary mechanism for choosing which aircraft to move. From signal strength, a Ground Station can gain a simple measure of how near an aircraft is to it. Moreover, an aircraft's transmissions are broadcast by their nature and can be received by any Ground Station in range and not just by that to which the packet is addressed. The relative signal strength can thus be measured at several locations and a good fix obtained on an aircraft's actual position. The XID frames transmitted by an aircraft can also contain information on its current position, and thus used to calibrate this mechanism.

Two mechanisms are specified by the VDL SARPs for Ground Initiated Handoff. The first is specified as "Ground Initiated Handoff" but is only possible when Handoff is to a Ground Station on the same frequency as the old one. To handle the general case "Ground Requested Aircraft Initiated Handoff" is also specified.

Under Ground Initiated Handoff, the new Ground Station sends an XID_CMD_HO to the aircraft in order to command the Handoff. This has to be sent on the same frequency as the old Ground Station as that is the frequency on which the aircraft is listening — hence the restriction. The aircraft will respond with an XID_RSP_HO and disconnects the old Ground Station with either a DISC Frame, or on timer expiry, as described for air-initiated Handoff.

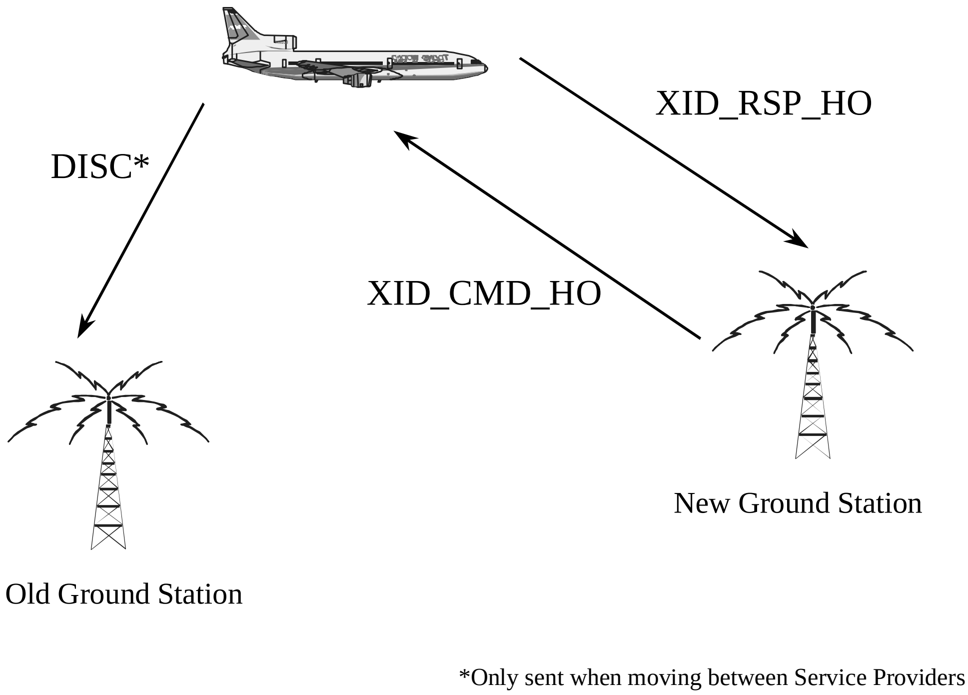

Figure 3-9 Ground Initiated Handoff

Under Ground Requested Aircraft Initiated Handoff, the current Ground Station also sends to the aircraft an XID_CMD_HO. However, this is distinguished from the previous case by setting the HDLC P/F bit to 0 instead of 1. The frame will also include a list of replacement Ground Stations and the frequencies to use to contact them. The aircraft responds as for an air initiated Handoff, typically using the supplied list of replacement Ground Stations - although it is permitted to change to a different Ground Station if it knows of one.

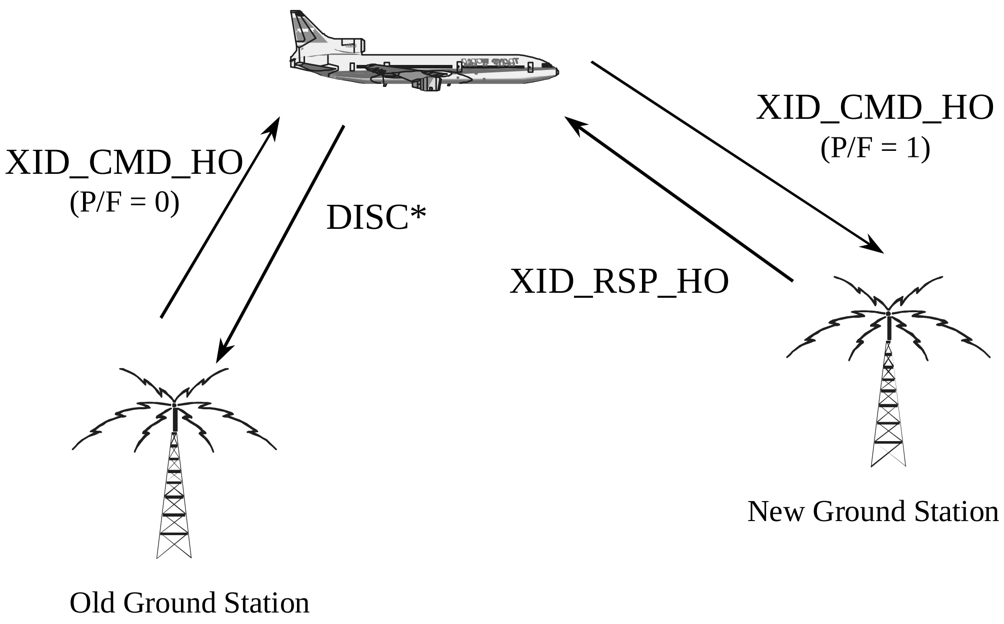

Figure 3-10 Ground Requested Aircraft Initiated Handoff

As with air initiated Handoffs, there are two mechanisms for maintaining the virtual circuits: *explicit subnetwork connection maintenance* and *expedited subnetwork connection maintenance.* These are very similar to the air-initiated cases and are illustrated in Figure 3-11 and Figure 3-12.

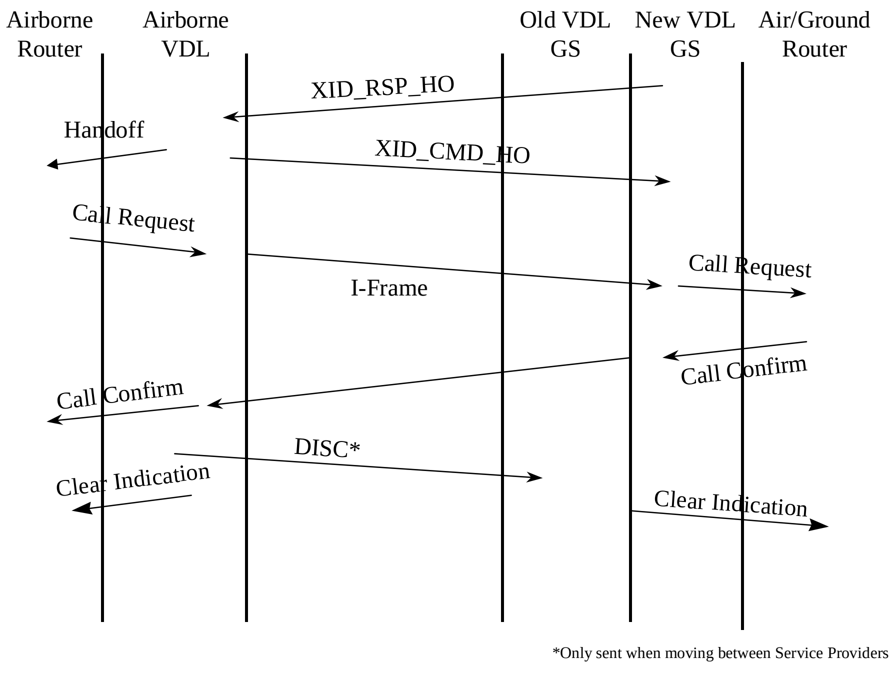

Figure 3-11 Explicit Subnetwork Connection Maintenance (Ground Initiated Handoff)

Note that with Ground Initiated Handoffs and expedited subnetwork connection maintenance, the Ground DTE is required to initiate the new calls (see Figure 3-12). This is so that the Call Requests are sent on the XID_CMD_HO and the Call Confirms on the XID_RSP_HO. The Ground DTE must therefore, in this one case, be able to initiate virtual circuits. With explicit subnetwork connection mainteance, it is still the aircraft that initiates the new virtual circuits.

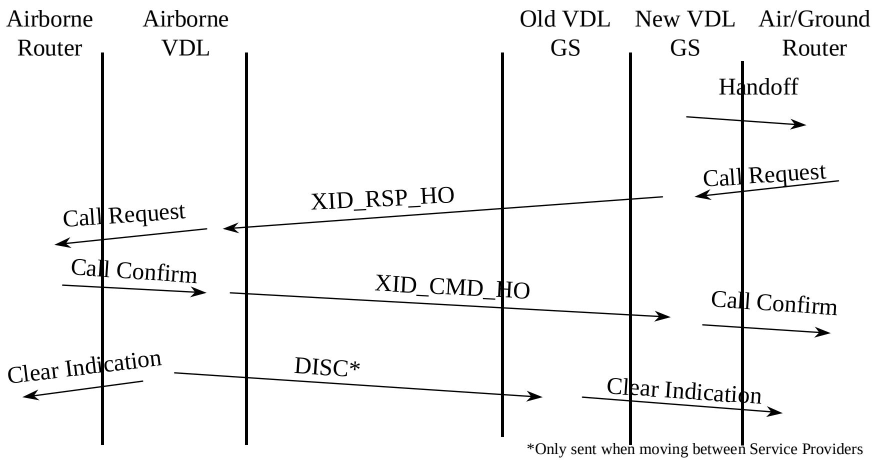

Figure 3-12 Expedited Subnetwork Connection Maintenance (Ground Initiated Handoff)

3.3.3.2 Aircraft Requested Ground Initiated Handoff

Procedurally, this form of Handoff is the reverse of the above, and is only permitted when moving between Ground Stations managed by the same LME. It may be preferred by some Service Providers in order to avoid an aircraft trying to use an already heavily loaded Ground Station.

Under Aircraft Requested Ground Initiated Handoff, an aircraft will send an XID_CMD_HO with the P/F bit set to 0 to its current or a proposed new Ground Station. The ground service will then respond with an XID_CMD_HO with the P/F bit set to 1 from the proposed Ground Station. Alternatively, the request may be rejected by returning an XID_CMD_LCR.

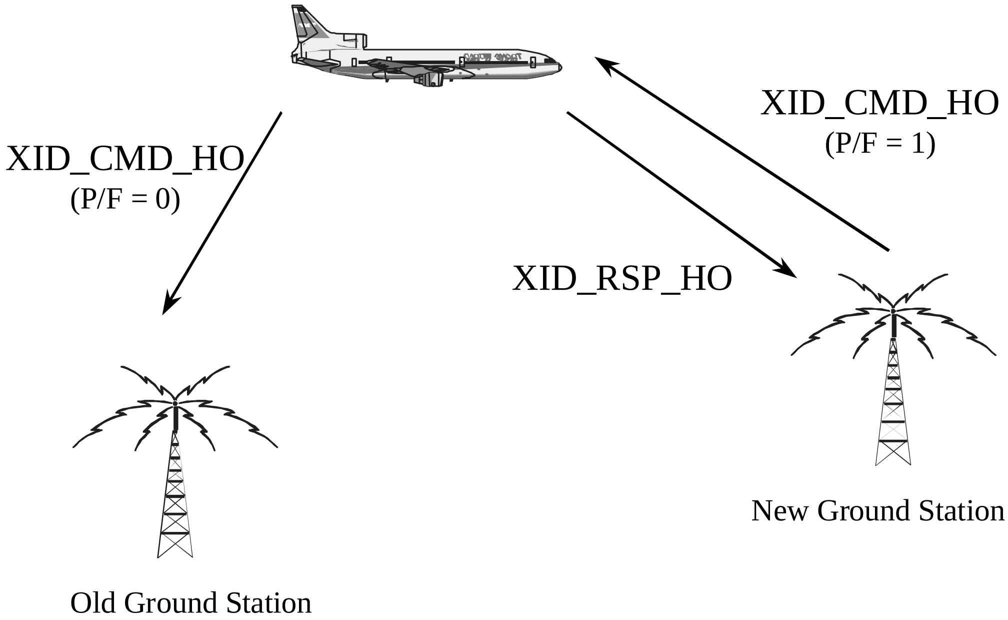

Figure 3-13 Aircraft Requested Ground Initiated Handoff

3.3.3.3 Ground Requested Broadcast Handoff

During recovery from a network failure or periods of heavy congestion, there may be a need to contact many aircraft in a short space of time, either to recover existing connections or to command those aircraft to move to a different Ground Station. In such situations, it can be very difficult to contact all such aircraft individually due to congestion.

This procedure allows a Ground Station to broadcast an XID_CMD_HO to all aircraft. This message will enumerate the aircraft to which it applies, the subnetwork connections (virtual circuits) that are maintained, and those aircraft for which a link Handoff has occurred. The effect of such a message is immediate and no confirmation is returned. Not all addressed aircraft will receive the message but that does not matter. The message is intended to reach as many aircraft as possible and this should be sufficient to reduce the congestion.

3.3.4 Loss of Service

When an aircraft loses contact with a Ground Station, it may try alternative frequencies identified when it logged on to the Ground Station (in the XID). More generally, it will return to scanning for VDL Service.

It is also important that loss of communication with an aircraft is identified rapidly by the Ground LME, and all virtual circuits to that aircraft cleared. This will be recognised by the ATN Router as the “Leave” event which will permit alternative routing to be used to the aircraft (e.g. via a satellite data link).

3.3.5 ATN Interconnection

3.3.5.1 Airborne Router

Logon to a new LME or Handoff is equivalent to the “Join Event” specified by the ATN SARPs. In either case, the XID provides a list of NETs of available ATN Air/Ground Routers and these are communicated by the Join Event to the Airborne Router.

ATN use of the VDL subnetwork is always air-initiated. That is it is the Airborne Router’s responsibility to react to the Join Event by establishing a virtual circuit to an identified Air/Ground Router. The Airborne Router will try to avoid transferring to a new Air/Ground Router, thus if the Join Event reports that an Air/Ground Router to which it is currently connected via VDL Mode 2 is still reachable, a new virtual circuit will be established to it, and the Data Compression parameters associated with the old virtual circuit to it are transferred to the new virtual circuit.

When a new Air/Ground Router is contacted, then the SARPs specified Route Initiation procedures are performed. A virtual circuit is established, ISH PDUs exchanged, and a BIS-BIS connection established.

When a virtual circuit to an Air/Ground Router is cleared and there is no alternative virtual circuit to that Router, then this is recognised as a “Leave Event”. Any BIS-BIS connection with the Air/Ground Router is terminated and the routes associated with it are withdrawn.

3.3.5.2 Air/Ground Routers

Under VDL, the ATN Air/Ground Routers take on an essentially passive role and wait to be contacted by an Airborne Router. On receipt of an incoming CALL REQUEST, the Air/Ground Router must first determine whether it has an existing virtual circuit with the same aircraft. If it does, then this is a result of a Handoff and the Data Compression context is carried over to the new virtual circuit. If a virtual circuit does not already exist with the Airborne Router, then an exchange of ISH PDUs must follow and a BIS-BIS Connection established.

As with the airborne case, when a virtual circuit to an Airborne Router is cleared and there is no alternative virtual circuit to that Router, then this is recognised as a “Leave Event”. Any BIS-BIS connection with the Airborne Router is terminated and the routes associated with it are withdrawn.

3.4 Operational Issues

There are a number of operational issues associated with the actual deployment of VDL Mode 2, including:

1. Frequency Assignment and Ground Station Deployment

2. Handoff Management

3. ATN Router siting

3.4.1 Frequency Assignment and Ground Station Deployment

The actual deployment of Ground Stations and the frequencies assigned to them will depend on a number of factors including site availability and elevation, the number of flight movements expected in the coverage area, and the availability of alternative frequencies.

In areas where only a low level of flight movements are expected, it will be sufficient to deploy single frequency Ground Stations operating on the Common Signalling Channel, such that there is continuous coverage with adequate signal strength over the whole region. However, this strategy will not provide a sufficient quality of service when the demands on the service exceed the capacity available and additional Ground Stations will have to be provided.

It is in the areas of overlapping coverage that problems may first be experienced, as the transmissions to and from the two Ground Stations will get in each other’s way. In such a areas, a third Ground Station operating on a different frequency will become very desirable.

In areas of high number of Flights, there may also be a need for Ground Stations operating on multiple frequencies.

3.4.2 Handoff Management

Regardless of the actual deployment of Ground Stations, the ideal situation is when Handoff is air-initiated. This is rather similar to “Free Flight”. The aircraft are, after all in the best situation to know the quality of service they are getting and the alternative sources of service and air-initiated Handoff lets them choose the best service for their needs.

However, when multiple frequencies are in use, or when Ground Stations overlap, an aircraft may make the best choice for itself, but which is not optimal for the network as a whole. In such cases, the Service Provider has to use the Ground Initiated Handoff or the Ground Requested Air Initiated Handoff procedures in order to ensure a better and more optimal distribution of aircraft to Ground Stations. Some Service Providers may also specify that aircraft perform the Air Requested Ground Initiated Handoff, rather than the Air-initiated procedures so that the Service Provider “polices” the requests and avoids an awkward situation developing.

In order to undertake this, the VME will require the availability of a significant amount of network management information together with the management services that permit it to command a Ground Station to initiate a Handoff. Specifically, the VME will need:

1. Information on each aircraft using a Ground Station including its identity and current signal strength (correlated with position where this is available), and the data transfer rate to and from it.

2. Information on channel loading, including collisions, retransmission attempts, corrupt packets and throughput.

3. “Actions” that enable it to command Ground Initiated Handoff

4. Event reports, such as Aircraft requests for Handoff.

Essentially, it will be necessary to define a Managed Object (MO) for the information associated with each aircraft and each Ground Station, in order to encapsulate the required functionality. These specifications are not part of the VDL SARPs, but are required for any operational implementation and should be defined by the EuroVDL project.

3.4.3 ATN Router Siting

This is an important issue as the ATN Router deployment can have a significant impact on the Air/Ground or Ground/Ground network loading, and there are three possible strategies that may be employed:

1. An ATN Air/Ground Router per Ground Station

2. A single central ATN Air/Ground Router

3. A distributed set of ATN Routers with the VDL subnetwork also operating as an ATN Routing Domain.

3.4.3.1 An ATN Air/Ground Router per Ground Station

This is probably the simplest model to deploy and requires a ground network to support only the interconnection of the ATN Routers; the VDL Ground Stations are connected directly to their local ATN Router. Figure 3-14 illustrates this configuration.

The Ground Station design - from the Ground Network point of view - is kept simple, as it supports only a single ATN Router and no other Ground Systems. All incoming CALL REQUESTS from an aircraft are passed to that ATN Router and there is no need for the Ground Station to interpret the Ground DTE Address.

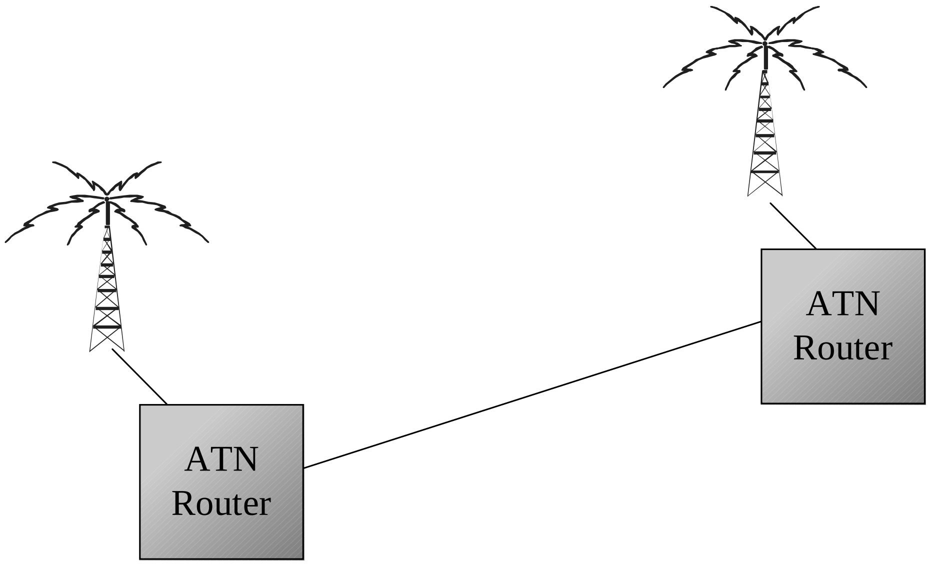

Figure 3-14 An ATN Router per Ground Station

On the Air/Ground side, each Ground Station reports the NET of its ATN Router in its GSIF. On initial logon to the network, each aircraft will connect through to that ATN Router. On Handoff, as each Ground Station advertises a different NET, aircraft will not attempt to re-establish a virtual circuit to the ATN Router of the old Ground Station, instead, they will make new virtual circuits to the ATN Router of the new Ground Station.

Everytime Handoff occurs, the full Route Initiation procedures will have to be undertaken; there is also no opportunity for preserving data compression tables. There is thus a significant air/ground overhead each time Handoff occurs, with a new BIS-BIS connection established and the uplink/downlink of routing information. This extra overhead will probably by acceptable in a trial, but not in an operational network.

3.4.3.2 A single central ATN Air/Ground Router

The overhead of a new BIS-BIS connection can be readily avoided if there is only a single ATN Air/Ground Router for the whole VDL subnetwork. This configuration is illustrated in Figure 3-15, and requires the availability of a Ground network (probably X.25) to interconnect the Ground Stations to the ATN Router.

The Ground Stations will now have to interpret the addressing information in CALL REQUESTs, so they can route calls from aircraft through to the ATN Router, and will thus need to incorporate the functionality of some sort of X.25 interworking unit (X.25 IWG). This will map the addressing information derived from the ATN Router's NET and passed in the called address extension field to the actual DTE Address of the ATN Router (on the ground X.25 network) and relay the call through to the ATN Router.

On initial logon to the VDL subnetwork, the normal Route Initiation procedures will still have to be performed in order to set up the BIS-BIS connection and exchange routing information. However, the benefit of this configuration comes on Handoff. On a Handoff, a new X.25 virtual call will be established between aircraft and ATN Router via the new Ground Station. However, the ATN Router will recognise this as coming from an aircraft with which it already is in contact and, as a result, will carry over the LREF Compression tables. No new BIS-BIS connection will be established as the virtual call is also recognised as supporting an existing adjacency. Even when the old virtual circuit is cleared, this does not affect the BIS-BIS connection, and the result is an efficient Handoff with no more overhead than the exchange of XID messages.

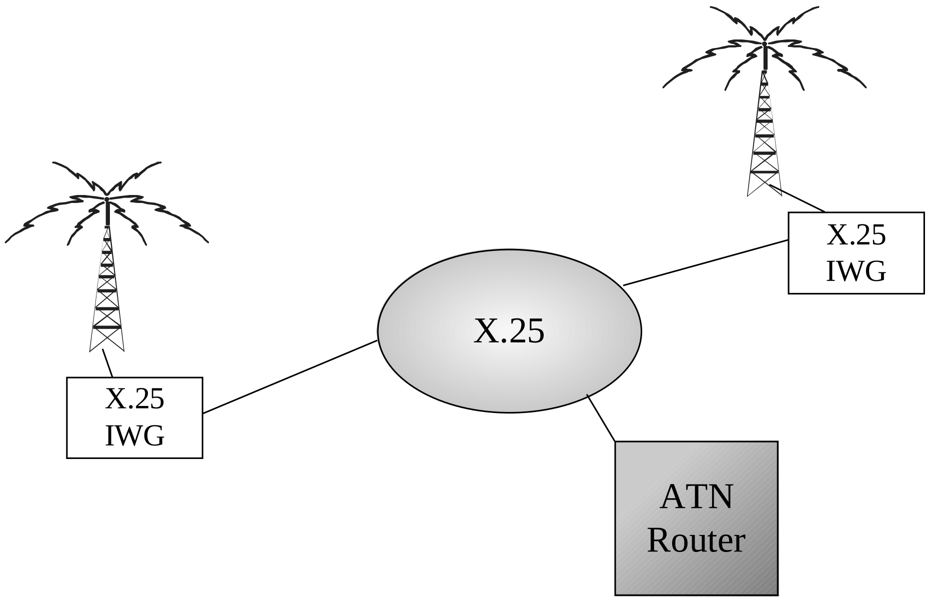

Figure 3-15 A Single Central ATN Router

However, it should be noted that if the Deflate compression algorithm is also used, this may need to be re-initialised if there is any loss or re-ordering of data during a Handoff. This is because this algorithm assumes a reliable stream mode datalink and is intolerant to loss or re-ordering of data.

The downside of this configuration is the impact on the ATN Router and the ground X.25 subnetwork of the potentially high number of virtual circuits that it will have to support and the rate of call establishment and clearing. When the IDRP simulations were performed for the ATN SARPs validation, a scenario of 2800 aircraft flying simultaneously in the ECAC area was assumed. If a VDL Subnetwork were to support a similar number of aircraft in a similar region, with an average of ten minutes between Handoffs in normal flight, and an average of one minute per Handoff (during which an aircraft would have two virtual circuits with the ATN Router), then the ATN Router would have to support at least 3080 simultaneous virtual circuits, with 2800 calls cleared and 2800 calls established every ten minutes i.e. 9.33 calls being cleared/established per second.

This is a very significant load for both the ATN Router and the X.25 packet switches supporting it. The TAR, for example, would need to have its subnetwork connection management software re-designed to handle this, assuming that the hardware platform can be configured to support this number of virtual circuits. The ATN Router is also a single point of failure and a more distributed solution is needed both to avoid the single point of failure to avoid the load placed on the ATN Router and nearby packet switches.

3.4.3.3 A Distributed Set of ATN Routers

More than one “central” ATN Router is certainly possible, with these Routers distributed around the ground subnetwork. Such routers can still form a single Routing Domain, and provide a network architecture that is really a “half way house” between an ATN Router per Ground Station and a single central ATN Router. That is positioning an ATN Router so that it serves a group or cluster of Ground Stations. This avoids the lack of scaleability inherent in a single central router, but still incurs IDRP and data compression overhead when moving between clusters. However, with intelligent deployment of Ground Stations and clusters the overhead per flight could be kept low.

3.4.3.4 ATN Router Tracking

The above can be further refined by permitting an aircraft to communicate with an ATN Router other than that which controls the cluster of Ground Stations through which they are currently connected to the VDL Network. This way, an aircraft could maintain its connection with the first ATN Router it connected to when it joined the VDL network and thus avoid IDRP overhead when moving between clusters.

This is possible because VDL Ground Stations can advertise access to multiple ATN Router NETs in their GSIFs - although the maximum length of the GSIF will impose a practical limit on how many ATN Routers can be so supported. If all Ground Stations advertise the NET of every ATN Router in their local Routing Domain then an aircraft can always keep in contact with the first ATN Router it contacted and this avoid the IDRP overhead on Handoff.

For this strategy to be effective, each Ground Station should advertise the list of NETs in a different order. This will effectively randomise the choice of ATN Router when an aircraft first logs on to the VDL subnetwork. Subsequently, as each aircraft goes through Handoff from Ground Station to Ground Station, it may keep in contact with the same ATN Router. This should spread the load over each ATN Router and works as long as there is essentially a random choice of ATN Router when an aircraft first logs on. Varying the order in which NETs are listed should achieve this as long as the aircraft entry point into the network is evenly distributed. However, if this is not true, then the aircraft will need to be random in their choice of ATN Router from the list given.

3.4.3.5 Forwarding Virtual Calls

However, whilst the above strategy will spread the load, it does still imply a comparatively high rate of virtual circuit establishment/clearing. To avoid this requires some sort of virtual circuit “forwarding” at the point of Handoff, as illustrated in Figure 3-16 for Ground Initiated Handoff.

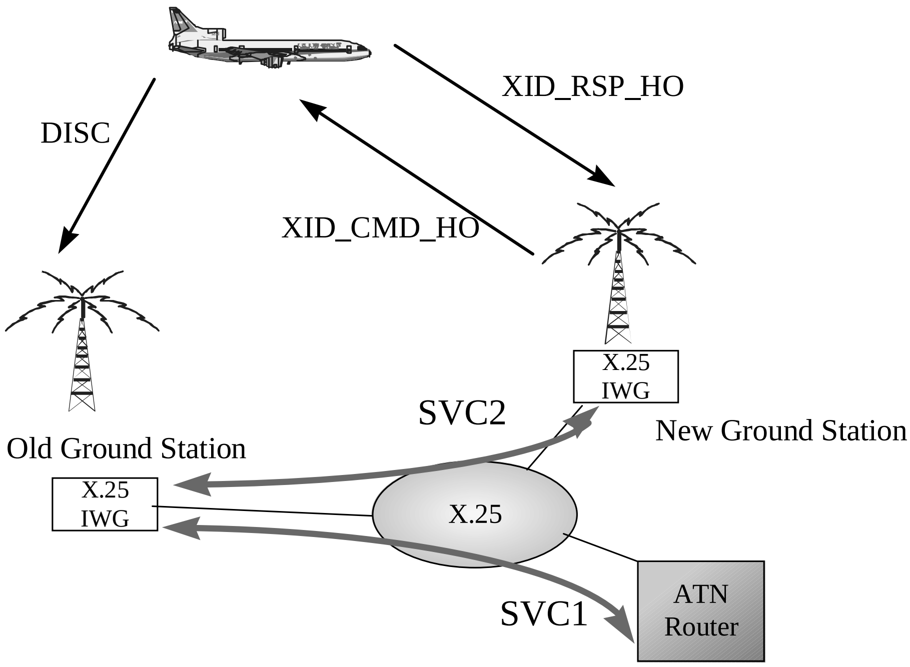

Figure 3-16 Virtual Circuit Forwarding

Prior to Handoff, the aircraft is connected through the "Old Ground Station" with SVC1 linking it to the ATN Router. When Handoff is commanded, SVC2 is established between the old and new Ground Stations and, indeed, for Ground Initiated Handoffs, the incoming call may be sufficient to cause the "New Ground Station" to send the XID_CMD_HO to the aircraft. Once Handoff is complete, both SVC1 and SVC2 remain in use with data relayed between them by the "Old Ground Station's" IWG. The successful establishment of SVC2 will also start the timer that results in the SVCs between the Old Ground Station and the aircraft being timed out (Note that the DISC is only needed when moving between Service Providers).

This approach means that no new virtual circuit needs to be established to the ATN Router and hence the overhead of doing this is discounted. However, as aircraft pass from Ground Station to Ground Station, the trail of virtual circuits will be become increasingly complex, increasing transit times and making network capacity planning difficult if not impossible. This is because the total number of SVCs (for all aircraft) will be difficult to predict, with the same data crossing the network many times. Loop detection and elimination may also be necessary.

Ideally, the X.25 ground network would provide a mechanism for joining two virtual circuits relayed through an IWG, and consolidating and optimising their path through the network. However, this feature will probably not be available in commercial products and the cost of custom development is unlikely to be justifiable.

3.4.3.6 Front End Routers

Such problems can probably be overcome by distributing the ATN Air/Ground Router itself, as illustrated in Figure 3-17.

IDRP is specified to use the CLNP internetwork protocol as its bearer protocol, which means that BISs can be separated by several intra-domain routers, typically implementing the IS-IS protocol. The IDRP standard itself says that BISs in different Routing Domains (such as an Airborne and Air/Ground Router) are linked by a common "real" subnetwork i.e. with no intervening routers. However, that is more a simplification rather than a requirement and, as long as a common subnetwork (e.g. VDL) is used to link an external BIS to all of its points of contact with another Routing Domain, then the requirements and assumptions of the IDRP standard are satisfied.

The benefit of using intra-domain routers is that the transport of CLNP packets is performed at the internetwork level using routers and this avoids all the problems associated with establishing and maintaining X.25 virtual circuits in the ground network. Data paths should always be optimal with minimal overhead. Moreover, more modern data network technologies such as Frame Relay and ATM can be readily used in the Ground Network.

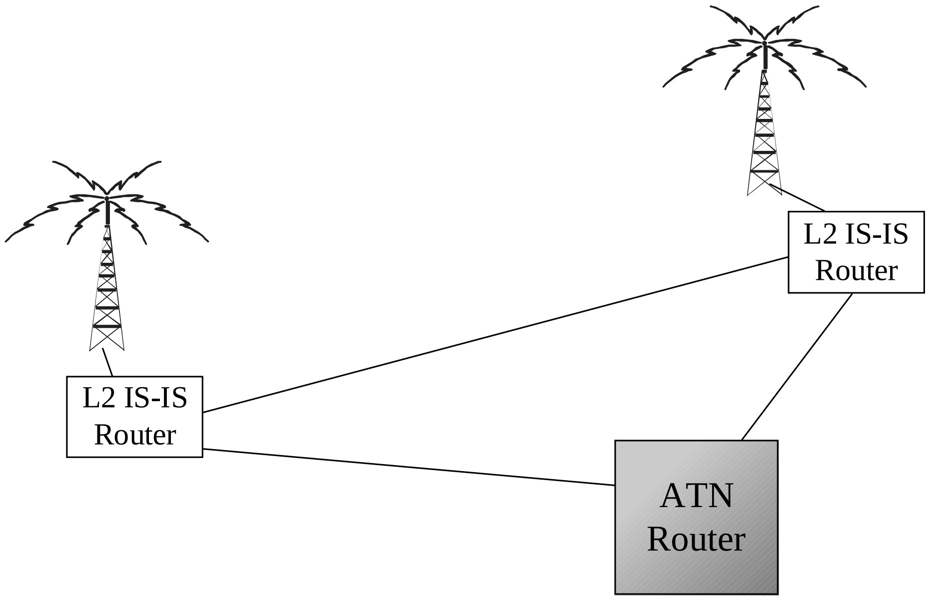

Figure 3-17 Using Intra-Domain Routers

In the figure, Level 2 IS-IS Intra-domain Routers (L2 IS-IS) are shown replacing the X.25 IWGs. These are directly connected to VDL Ground Stations. The importance of using L2 IS-IS Routers as these routers is, whilst primarily intra-domain routers, they are permitted to support Inter-Domain connections. These must use externally derived information (e.g. from the Ground Station) to make such a connection, but they are able to report the availability of the route, dynamically, in their Level 2 Link State Protocol (L2 LSP) unit. Provided that the ATN Router (the BIS) is also a L2 IS-IS Router, it can receive such routing information and hence keep in contact with a given aircraft regardless of which Ground Station it is accessed through.

In practice, all Ground Stations that are part of the same Routing Domain (i.e. VDL subnetwork) would advertise the NETs of all “central” ATN Routers (BISs) in their GSIFs - multiple ATN Routers will still need to be supported in order to avoid a single point of failure.

When an aircraft logs on to the network, it send a CALL REQUEST to the chosen ATN Router. Regardless of which one is specified, this is passed on the to local L2 IS-IS Router. This responds to the CALL REQUEST and starts the Route Initiation procedures by uplinking an ISH PDU with the intended BIS’s NET in it. The Router also adds the NSAP Address Prefix for the aircraft (as derived from the downlinked ISH PDU) to its own L2 LSP which is flooded through the Ground Network supporting the VDL Mode 2 subnetwork. All L2 Routers in the Routing Domain, including the ATN Router(s) are now able to route uplink CLNP packets to that router and hence to the aircraft.

From the ATN Router's viewpoint, the receipt of a L2 LSP including a "new" reachable address prefix, will be the equivalent of the "Join Event" identified in the SARPs, and will to be interpreted as such, and thus to cause the BIS to carry out the Route Initiation procedures for BIS-BIS connection establishment.

Once this stage is passed, the L2 IS-IS router will forward all downlinked CLNP packets, including those containing IDRP BISPDUs to their individual destinations. For BISPDUs, this will be the ATN Router, as identified by its NET as the destination address. All CLNP packets received by the L2 IS-IS Router and addressed to destinations on board the aircraft will be forwarded over the air/ground data link to the aircraft. The BIS-BIS connection can thus now be established and user data exchanged.

On Handoff, the aircraft will contact a new Ground Station and attempt to re-establish its virtual circuits to the same ATN Router (the aircraft is not aware that the circuits terminate in an L2 IS-IS Router). The new Ground Station may well be connected to a different L2 IS-IS Router, and it is this L2 IS-IS Router that will receive and accept the CALL REQUESTs from the aircraft. This will, as above, accept the call, uplink an ISH PDU and add the aircraft's NSAP Address to its LS LSP. However, the aircraft does not see a change in the ATN Router it is connected to and will hence (correctly) not try to establish a new BIS-BIS connection. When the DISC is received by the old Ground Station or the Handoff timer expires, its L2 IS-IS Router will see the loss of the virtual circuit and remove the aircraft's NSAP Address Prefix from its L2 LSP. The other L2 Routers in the Ground Network will thus see the change in connectivity and route their uplink packets to the aircraft appropriately.

This strategy provides a fully distributed approach to the handling of aircraft and is not dependent upon any one type of ground network. It is also readily scaleable with no single point of failure. However, there is one serious downside as described, in that whenever an aircraft moves between Ground Stations that are attached to a different L2 IS-IS Router, then the compression state is not preserved, resulting in a short-term increase in protocol overhead. This is undesirable. However, this problem may be overcome by implementing a management subprotocol to pass the compression state from one router to another. Essentially, when Handoff occurs the new L2 Router would need to request and obtain the compression state information from the old L2 Router (it knows this router by inspection of the L2 LSPs received from all such routers). A simple request/response protocol will be sufficient for this process, perhaps sent direct over CLNP or the CLTP. A CMIP "GET" could alternatively be used. The same mechanism can also be adapted to control the Handoff process and to ensure that an aircraft does not maintain two connections to the same LME.

Once this is implemented, the result should be an optimal network architecture with minimal load on the ground and air. In practice, the number of L2 LSPs generated may be an issue. The L2 Routers will need to send one out for each change in aircraft activity that occurs - although several changes can be reported in the same L2 LSP, which itself will act as a form of rate limitation when under high load. However, this is one issue that should be investigated.

4. Proposed EuroVDL Network Architecture

The preceding section has analysed the VDL Mode 2 Subnetwork and, in particular, the options for Ground Network design and ATN Router deployment. This has identified that the preferred goal architecture comprises a distributed network of VDL Mode 2 Ground Stations each "front-ended" by a L2 IS-IS Router. A Ground Network then interconnects these Routers with ATN Air/Ground Routers either directly or via other L2 IS-IS Routers. Any suitable networking technology may be used to interconnect these routers and the VDL Mode 2 Ground Network is not restricted to X.25. All the L2 IS-IS Routers and ATN Routers supporting the VDL Ground Stations under a single Network Administrator (i.e. a VME) from a single Routing Domain.

However, the purpose of a trial is to validate such a preferred architecture both by implementing it and comparing it with the alternatives. The trial will also need to build the network gradually in order to gain operational experience, possibly backed by simulations of different network architectures. The purpose of EuroVDL is to build a pilot VDL Mode 2 Network in Europe, and to do so with the minimum of risk. The proposed EuroVDL Architecture is thus that which can be implemented in the shortest time and with the minimum of new development. While this may be developed on at a later date to a more optimal architecture, this is outside of the scope of the current project.

For EuroVDL, the primary objective is the implementation of a (non-optimised) VDL Mode 2 service for a limited number of aircraft with the minimal amount of new development. Subsequent to the project, this can then be developed into the goal architecture.

It is also recognised that the airborne avionics will have to be common to both EuroVDL and any later development. Therefore a profile for air/ground VDL Mode 2 communications will need to be developed that is compatible with both the EuroVDL architecture and later developments, and implemented by the Trials avionics.

4.1 Proposed EuroVDL Architecture

4.1.1 Objectives

1. Earliest possible implementation of a EuroVDL Service
2. Use of both the ProATN and additional EuroVDL Ground Stations
3. Operation on a single frequency - the Common Signalling Channel (CSC)
4. Deployment of an ATN Service supporting ADS
5. Air-initiated Handoff only
6. No attempt at ATN optimisation during Handoff, or co-ordinated Ground Station operation.

4.1.2 Network Architecture

Figure 4-1 shows the proposed siting plan and coverage for both the ProATN and EuroVDL Ground Stations. It is proposed that all will operate on the same frequency (the Common Signalling Channel) and as a single VDL subnetwork. It is not believed that the operation on a single frequency will not cause a problem for a limited number of trials aircraft. As more aircraft are brought into the trial, it will later enable the possible conflicts with overlapping coverage areas to be studied.

The EuroVDL Ground Stations will be located at: Gatwick, Frankfurt, Nice and Rome. It is proposed to link them with the ProATN Ground Stations at Paris, Amsterdam and Toulouse to create a network with good coverage of Western Europe. However, the use of ProATN Ground Stations is subject to confirmation. It has also been proposed to add futher Ground Stations at Geneva (SITA) and Dusseldorf (DFS). These will permit continuity of coverage and support a proper evaluation of Handoffs.

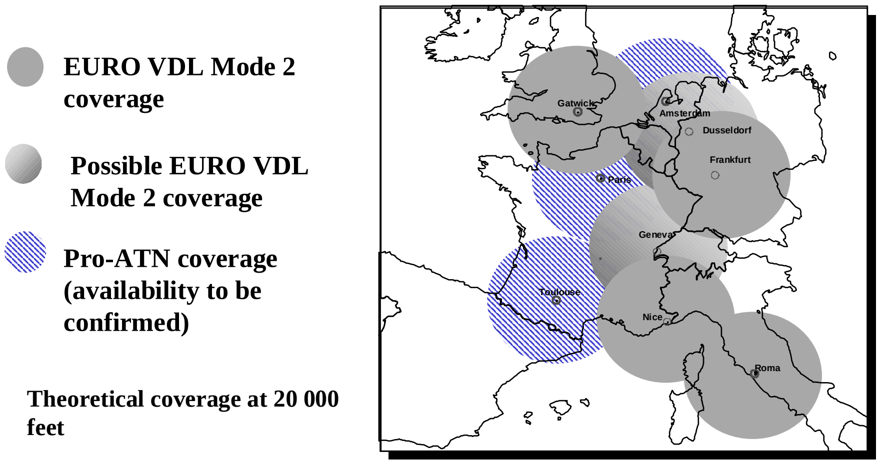

Figure 4-1 Combined EuroVDL and ProATN Ground Station Coverage

The proposed Ground Architecture is illustrated in Figure 4-2. It is proposed that generally a single Air/Ground ATN Router is co-located with each Ground Station (if not actually on-site then directly connected), and these ATN Routers are interconnected to form a single Routing Domain. However, two “clusters” will also be implemented if the Geneva and Dusseldorf Ground Stations are made available. That is Geneva will be clustered with Nice and Dusseldorf with Frankfurt.

The actual routing topology and underlying data links used to interconnect the ATN Routers is not significant and the Router-Router interconnections shown in the figure are for illustration purposes only. It is expected that existing national networks such as Capsin, Renar and Rapnet will be used to support the interconnection of the ATN Routers. Any of these ATN Routers can also support interconnection (at the inter-domain level) to other trials networks such as Petal-II.

The existing ATIF Network Management Centre (NMC) is proposed as the main network hub, and an ATN Router (Ground-Ground) at this point will provide the interconnection with ProATN. This will manage the ATN Routers, but will not provide VDL Management.

In EuroVDL, there will be no attempt at co-ordinated operation of the Ground Stations or at minimising the ATN protocol overhead associated with Handoff. Therefore, only air-initiated Handoffs will be supported and each Handoff between clusters will result in an aircraft connecting to a new ATN Router (i.e. a BIS) and the full route initiation procedures will be performed including the establishment of a BIS-BIS connection and the exchange of routing information. A simple ground protocol will be developed to support Handoff and to ensure that the “Old” Ground Station always starts the timer needed to time out the old data link.

Management information will be collected for analysis of network performance from both Ground Stations and ATN Routers.

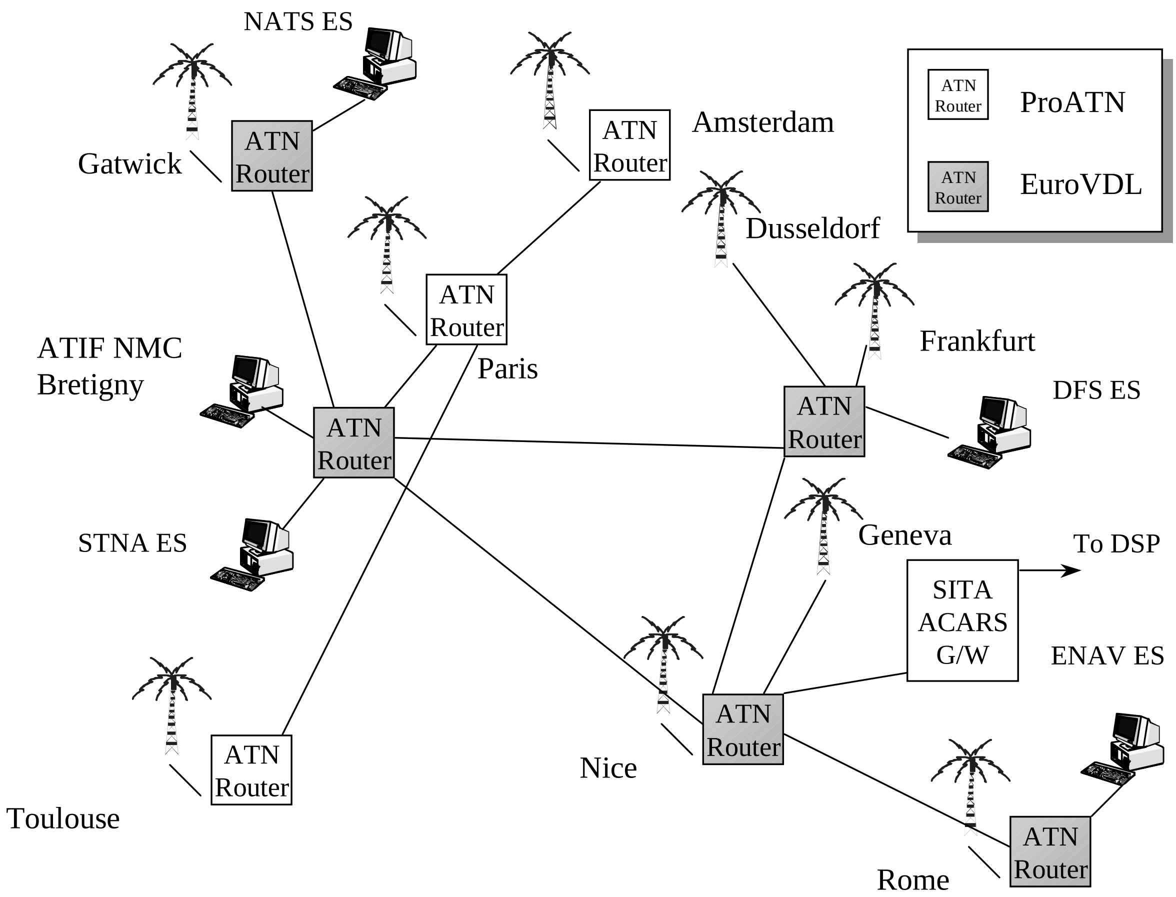

Figure 4-2 Proposed EuroVDL Network Architecture

4.1.3 Evaluation

The key success criteria for phase one will be the provision of a working VDL Mode 2 service for the trials aircraft, and the provision of performance data from the albeit limited number of aircraft involved.

4.2 Possible Follow-on Development

4.2.1 Objectives

Subsequent to a successful conclusion of the project, the EuroVDL network may be developed into a more optimal architecture. This is not expected to be a sudden transition from one architecture to another, but will instead involve a phased introduction of new features, and evaluation until the goal architecture is achieved. The objectives of such a development should be:

1. The evolutionary implementation of the VDL Mode 2 Goal Architecture

2. The implementation of a distributed Ground Network of ATN Routers including the use of Level 2 IS-IS Routers for Ground Station interconnection, and the exchange of Compression State between such Routers

3. The support of Ground Initiated/Requested Handoffs and Broadcast Handoffs

4. The provision of online Network Management information at Ground Stations and ATN Routers in order to support centralised and co-ordinated Handoff, fault management and capacity planning

5. The introduction and use of additional VDL Frequencies and the active management of aircraft frequency use through Ground Initiated Handoffs in order to support the efficient use of available spectrum.

6. The development of an Operations Manual that will document the procedures for efficient Network Management. (Note: it is expected that such a document will be developed in successive versions during phase 2).

4.2.2 Network Architecture

Under such a development, it is anticipated that further Ground Stations will be introduced at sites to be specified and that some of the existing sites will be equipped with multiple Ground Stations operating at additional frequencies. Both of these developments are outside of the scope of this paper.

It is proposed that the commencement of the development of an optimal architecture is marked by the re-configuration of the EuroVDL Air/Ground ATN Routers to L2 IS-IS Routers. The remaining Ground-Ground Router at Bretigny will provide the core BIS functionality. It is also proposed that the Nice Air/Ground Router is a dual L2/ATN Router in order to provide backup to Bretigny and to retain the inter-domain connection to SITA. The re-configured ATN Routers will also include the capability to exchange compression state information (see 3.4.3.6). The revised architecture is illustrated in Figure 4-3.

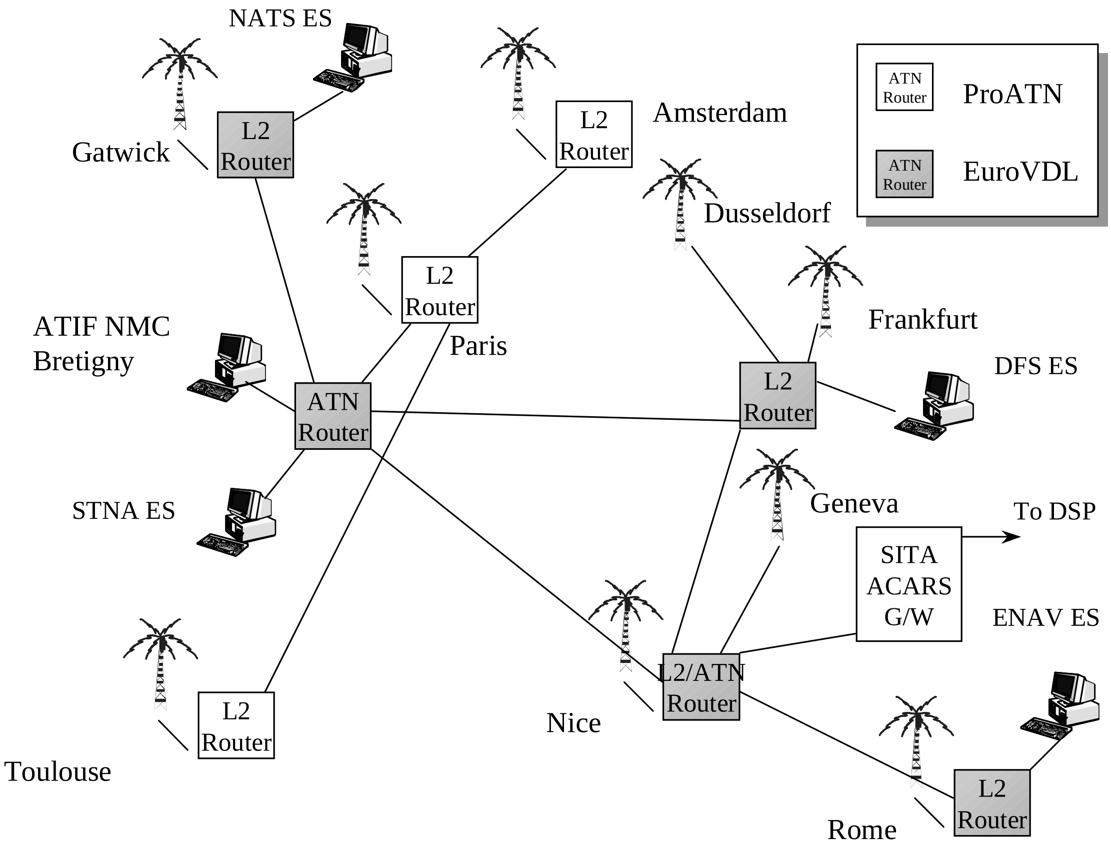

Figure 4-3 Follow-on Router Deployment

With two remaining BISRouters, the architecture can also demonstrate no single point of failure. This revised architecture will be sufficient to demonstrate and evaluate optimised Handoffs with minimal ATN protocol overhead.

Subsequent to this, a Network Management Centre (NMC) may be introduced to provide central monitoring of the network and for the co-ordination of Ground Initiated Handoffs, etc. The EuroVDL NMC will need to collect information on:

- the performance of each Ground Station and associated channel performance
- aircraft location (from relative signal strength) and per aircraft network performance data,

and thereby determine where there is a mis-match in the network between demand and available capacity, and to rectify this, where possible, by moving suitable aircraft between Ground Stations through Ground Initiation and Ground Requested Handoffs. During extreme congestion, it may also command Broadcast Handoffs.

In order to achieve this, a Management Protocol (probably CMIP) must be implemented and Managed Objects defined to represent both Ground Station and ATN Routers (both L2 and BIS Routers). These MOs must be able to provide the management information required by the NMC and to be able to command Handoffs.

Following the implementation of the NMC, Ground Stations operating at additional frequencies may now be introduced and the EuroVDL can evolve towards an operational service.

5. Conclusion

This paper has analysed the VDL Mode 2 SARPs and the implications of the SARPs for Ground Network design. It has identified an optimal architecture with a tight integration between the ATN and the VDL Mode 2 Ground Network. A Network Management strategy is also required in order to match demand to available capacity through use of the Handoff mechanism.

In line with the project requirements, the implementation of the EuroVDL trials network is proposed with a non-optimal architecture, but permitting the implementation in the shortest time and with the least new development. This may be later developed into a more optimal architecture albeit outside of the scope of the current EuroVDL Project,

Following on from the paper, it is anticipated that the following specifications will need to be prepared within the context of the EuroVDL project:

1. A Profile for Ground Station and Avionics support of the VDL Mode 2 Air/Ground protocols.
2. VDL Mode 2 Ground Station Specification
3. Specification of the ATN Routers (BISs) proposed for the VDL Ground Network.
4. A concrete siting plan for Ground Stations and Routers, including Ground Station and Router address assignment, and the specification of the data links interconnecting them.

In the proposed follow-on development, further specifications will also have to be developed:

1. Managed Object specifications for both Ground Stations and ATN Routers

2. Specification of the Level 2 IS-IS Routers proposed for the VDL Ground Network.

3. The specification of the EuroVDL Network Management Centre.

4. The development of the EuroVDL Network Operations Manual.

Outside of the scope of this paper are the proposed ADS trials application and interconnection with other trials, such as Petal II.