ATNP/WG2
WP/495

EUROCONTROL

Proposed Guidance Material in Support of VDL Handoffs

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AERONAUTICAL TELECOMMUNICATIONS NETWORK PANEL

Working Group 2

Hawaii 18-22 January 1999

SUMMARY

Action 16/7 arising from the 16th meeting of ICAO/ATNP/WG2, required "… to prepare a PDR proposing modifications to the VDL SNDCF. The PDR was required to indicate any needed changes to the VDL Mode 2 SARPs. This paper proposes Guidance material to accompany the SARPs changes.

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ATN PROJECT

Proposed Guidance Material in Support of VDL Handoffs

ATN Ref.	: DED6/ATNCT/ProATN_Sup/DCI/AW_45
Author	: Tony Whyman
Rev. No.	: Issue 1.0
Date	: 01/01/99

DOCUMENT CONTROL LOG

SECTION	DATE	REV. NO.	REASON FOR CHANGE OR REFERENCE TO CHANGE
	01/01/99	Issue 1.0	

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1. Introduction

Action 16/7 arising from the 16th meeting of ICAO/ATNP/WG2, required "Mr. Whyman to prepare a PDR proposing modifications to the VDL SNDCF. The PDR should also indicate any needed changes to the VDL Mode 2 SARPs. This was after consideration of WP/470 on the probable need for ATN SARPs changes to accommodate VDL Mode 2 handoffs.

SARPs changes have now been proposed. This paper provides Guidance Material to accompany the proposed changes. Two changes are proposed to the CAMAL:

1. Part IV: section 3.4.12 is added to introduce Subnetwork Handoff in the ATN Routing Chapter.

2. Part IV: section 3.6.4.1 VDL Mode 1 and Mode 2 Subnetworks is amended to include a detailed description of the Join, Leave and Handoff events at the VDL Subnetwork level. The opportunity is also taken to enhance the VDL Guidance Material to include text from WG2/WP469.

The proposed changes are attached.

3.4.12 Subnetwork Handoff

Terrestrially based Mobile Subnetworks typically deploy a number of fixed Ground Stations communicating with Mobile Systems that are in “line of sight”. As the mobile changes its position, it may go out of sight of one Ground Station and into the coverage of another. Handoff of communications between the Ground Stations has thus to be implemented if contact is to be maintained.

In the case of the Mode S Subnetwork, this Handoff process occurs entirely within the subnetwork and is not made visible to the subnetwork user. It thus does not affect the ATN Internet. However, the VHF Digital Link (VDL) takes a different approach, and makes this Handoff visible to the subnetwork user: the user is informed of the Handoff and has to explicitly set up new virtual circuits via the new Ground Station and which are to replace those currently in existence. The old virtual circuits are then cleared by the VDL subnetwork.

VDL Handoff is this visible to the subnetwork user and does impact on the ATN Internet. Two cases need to be considered: (a) when Handoff is between Ground Stations and a change of Air/Ground ATN Router is required, and (b) when communication is maintained with the same Air/Ground ATN Router.

In the first case, Handoff may appear as a “Join Event” to the Airborne Router identifying the new Air/Ground ATN Router as the destination DTE Address and, some time later, a “Leave Event” for the old Air/Ground ATN Router. No new ATN Internet procedures are thus required, and as far as the Airborne Router is concerned, the result is no different to moving between Mobile Subnetworks.

In the second case, the same approach could be taken. However, this would be unnecessarily inefficient, as the overhead of re-establishing the data compression context and performing the Route Initiation procedures would be performed when otherwise unnecessary. Instead, the notion of a “Handoff Event” is introduced to cover this case.

Although the VDL Subnetwork is always Air Initiated from the point of view of data link establishment, Handoff may be Air or Ground Initiated and, likewise, the Handoff Event may be received by an Airborne or an Air/Ground Router. In either case, the response to a Handoff is the same: new virtual circuits are set up via the new Ground Station, with the remote ATN Router, and in order to replace the existing ones, which are cleared by the subnetwork after a suitable timeout has elapsed. Note that formal responsibility for responding to a Join Event and instructing the SNDCF to initiate the new virtual circuits rests with the IS-SME. The VDL Subnetwork itself does not automatically establish the new virtual circuits.

As the new virtual circuits are between the same pair of DTE Addresses, the SNDCF automatically places them in the same subnetwork connection group. Provided that the “Maintenance/Initiation of Local Reference Directory” option was selected when these subnetwork connections were established, the SNDCF will then automatically handoff the data compression context from old to new virtual circuits.

A detailed discussion of VDL link establishment, termination and Handoff may be found in section 3.6.4.1.

3.6.4.1 VDL Subnetworks

3.6.4.1.1 Introduction

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

This subnetwork can run in at least three modes:

Mode 1. A minimum shift keying modulation scheme using a p-CSMA procedure for Media Access.

Mode 2. A differentially encoded phase shift keying modulation scheme using a p-CSMA procedure for Media Access.

Mode 3 A differentially encoded phase shift keying modulation scheme using a TDMA procedure for media access. VDL Mode 3 is especially suitable for voice communications.

Neither VDL Modes 1 or 2 provide for virtual circuit priority. However, VDL Mode 3 does support virtual circuit priority.

The VDL airborne unit uses a VHF Data Radio (VDR) which communicates with a Remote Ground Station (RGS) interconnected via Ground WANs with Air/Ground ATN routers. The RGS are ground station equipment with radio antenna and WAN access capabilities, and map the air/ground ISO/IEC 8208 services to their ground network equivalents and vice-versa.

3.6.4.1.2 General VDL mode-1 and mode-2 characteristics

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 Aircraft Communcations Addressing and Reporting System (ACARS) communications service, that has been serving commercial airlines for over twenty years, with an evolution that extends through VDL Mode 1 to VDL Mode 2.

ACARS itself is a character mode communications service using modems that provide a 2400 bps data 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. VDL Mode 1 was essentially an interim low risk proposal, and the substantial gain in throughput with D8PSK makes VDL Mode 2 much more attractive than either ACARS or VDL Mode 1, and the rest of this Guidance Material thus refers to VDL Mode 2 only.

The ICAO VDL SARPs only specify the air/ground data link procedures and protocols for VDL. 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. The specification provides 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 3.6-1 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. The expectation is that VDL Mode 2 is used in conjunction with the ATN. An aircraft thus 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.

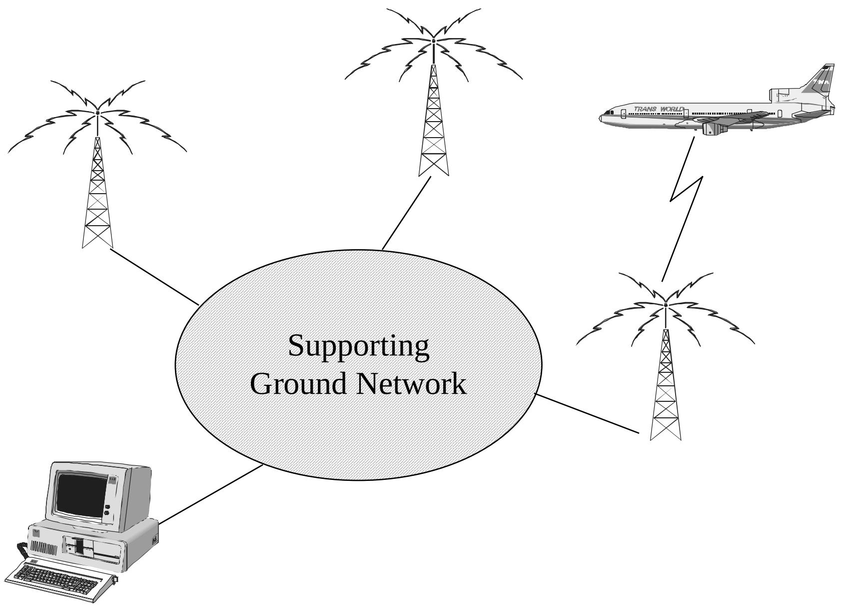

Figure 3.6-1 VDL Network Concept

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.

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 are being used to support an end-to-end application, then that application would have to cope with the ensuing disruption.

However, using VDL Mode 2 via the ATN hides the changes in virtual circuits from end-to-end communications. 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.

3.6.4.2 Protocol Architecture

The protocol architecture for VDL Mode 2 is illustrated alongside in Figure 3.6-2. 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.

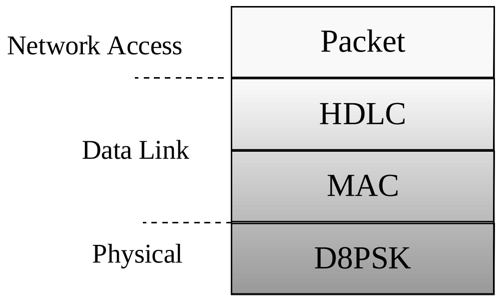

Figure 3.6-2 VDL Mode 2 Protocol Architecture

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.

3.6.4.2.1 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 ppersistent 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.

3.6.4.2.2 Aviation VHF Link Control (AVLC)

The AVLC 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.

3.6.4.2.3 The VDL Packet Layer

The VDL Packet Layer is an implementation of ITU-T X.25 as specified in ISO 8208. It specifies a number of otherwise 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.

Note that the actual ground DTE address is always returned back to the Airborne Router as the Called Address in the CALL ACCEPT packet. The optional X.25 user facility "Called Line Address Modified Notification" is used to indicate that this returned address is not the same as the original called address.

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.

3.6.4.3 Operational Procedures

3.6.4.3.1 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*.

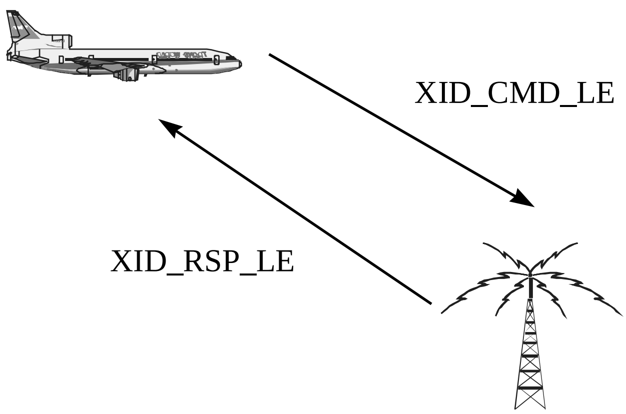

Figure 3.6-3 Message Exchange for VDL Data Link Initiation

3.6.4.3.1.1 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 3.6-4.

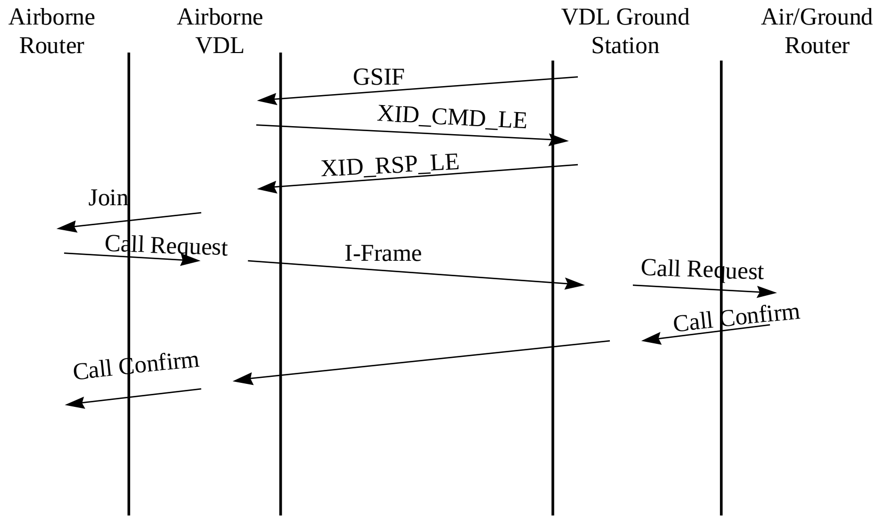

Figure 3.6-4 Explicit Subnetwork Connection Establishment

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.

3.6.4.3.1.2 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 3.6-5.

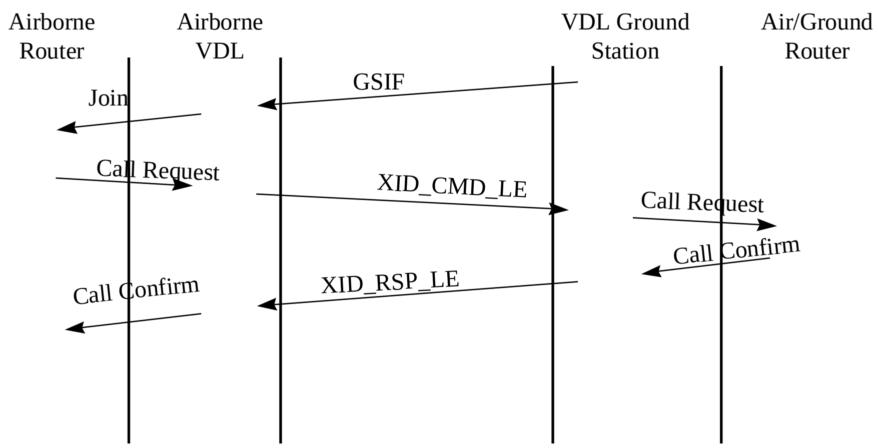

Figure 3.6-5 Expedited Subnetwork Connection Establishment

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 chance 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 addressed 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 addressed local users. Route Initiation will then proceed as described in the SARPs.

3.6.4.3.2 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.

3.6.4.3.2.1 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.

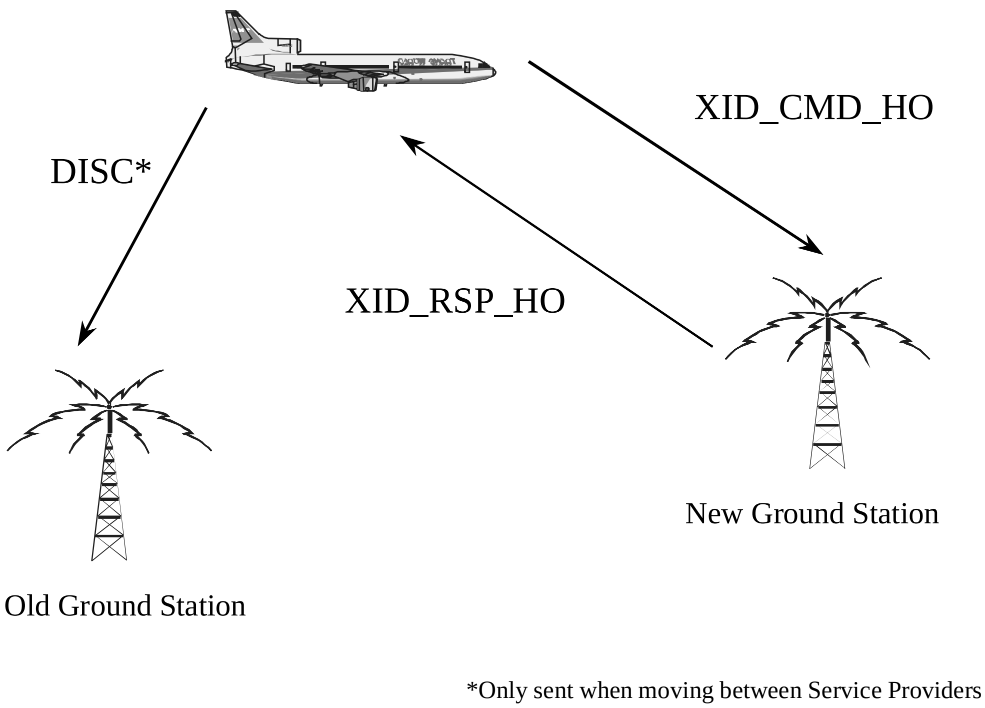

Figure 3.6-6 Air-initiated Handoff

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.

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.

However, it should be recalled (see 3.6.4.2.3), that the actual DTE Address of the Air/Ground Router that the Airborne Router is in contact with is not necessarily the same as that advertised in the GSIF. This may be an alias for many Air/Ground Routers (especially if they are in the same Routing Domain). Hence, if virtual circuits are to be established, on Handoff, to exactly the same Air/Ground Router, the Called Address returned in the CALL ACCEPT on link establishment must be used and not the VDL specific address given in the GSIF. This requires that the Airborne Router keeps knowledge of the relationship between the VDL Specific and Ground DTE Addresses while in communication with an ATN Router.

On the other hand, acceptance of Ground X.121 addresses by Ground Stations is optional and if the feature is not supported (it is declared as a capability on the GSIF), then the VDL Specific Address has to be used. It follows that Service Providers must implement this capability if VDL Specific Addresses are not unique. Airborne implementations must always be able to use it.

Co-ordination between VDL and ATN Internet components is defined as being via a “Handoff Event”. This is an event reported by the VDL subnetwork to the ATN Router and identifies the VDL specific DTE Address of destination(s) affected by Handoff and the Ground Station through which the new virtual circuits should be routed.

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. In this case, the VDL Handoff is reported to the ATN Internet components as a Join event for the new Air/Ground Router and, sometime later, a “Leave” event for the old Air/Ground Router.

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.*

3.6.4.3.2.2 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 3.6-7 for air initiated Handoffs.

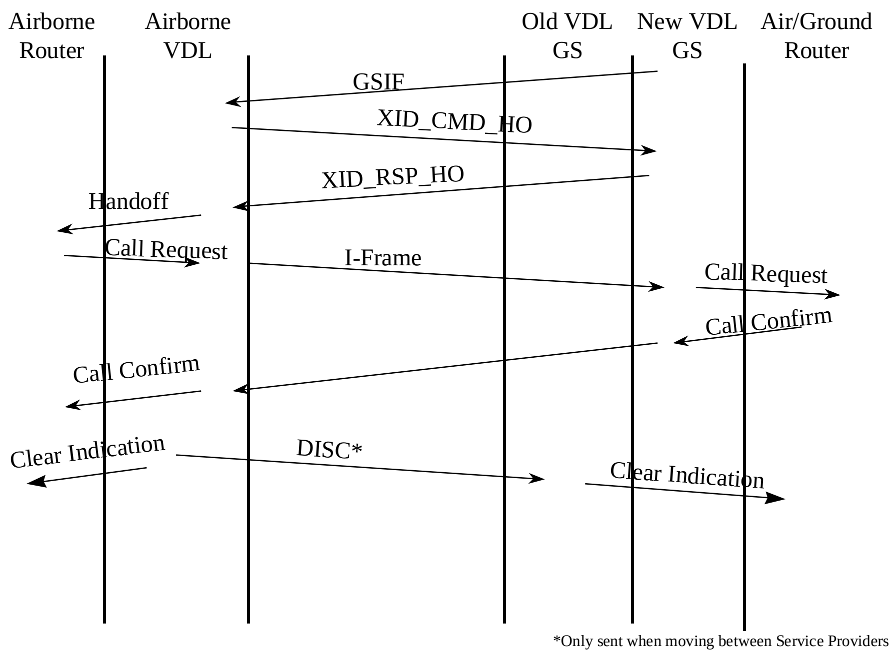

Figure 3.6-7 Explicit Subnetwork Connection Maintenance (Air Initiated Handoff)

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.

3.6.4.3.2.3 Air Initiated Handoff with expedited subnetwork connection maintenance

With the expedited link establishment 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.

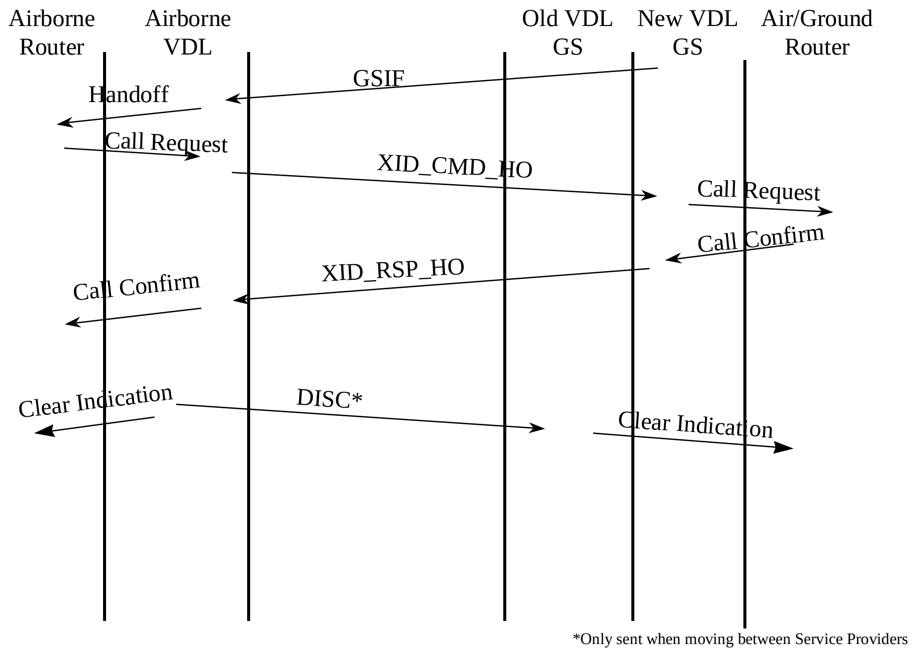

Figure 3.6-8 Expedited Subnetwork Connection Maintenance (Air Initiated Handoff)

3.6.4.3.2.4 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 geographicaly separate 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.

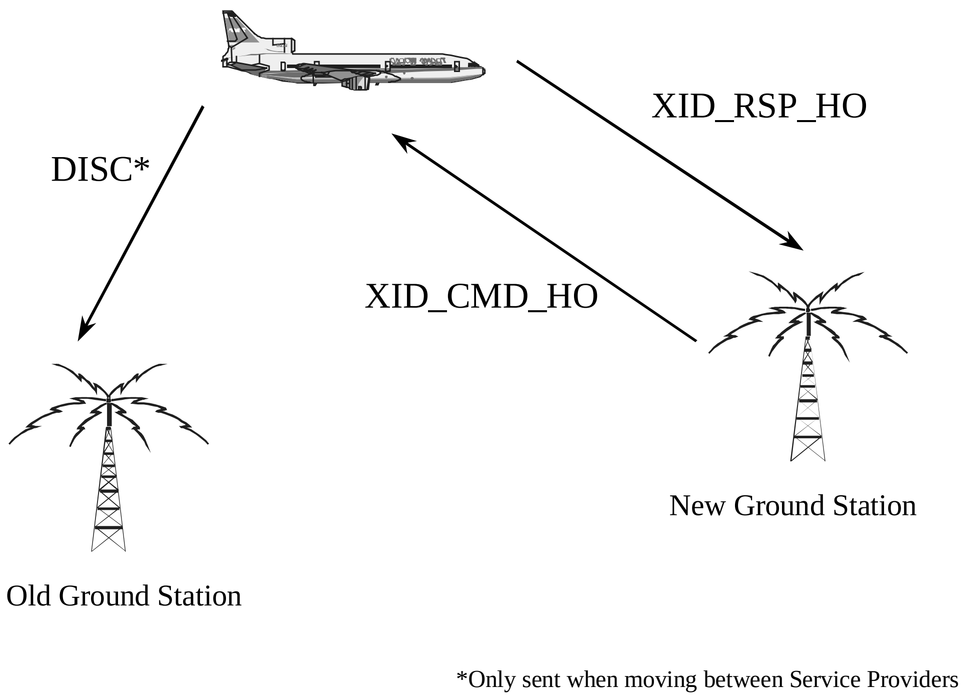

Figure 3.6-9 Ground Initiated Handoff

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.

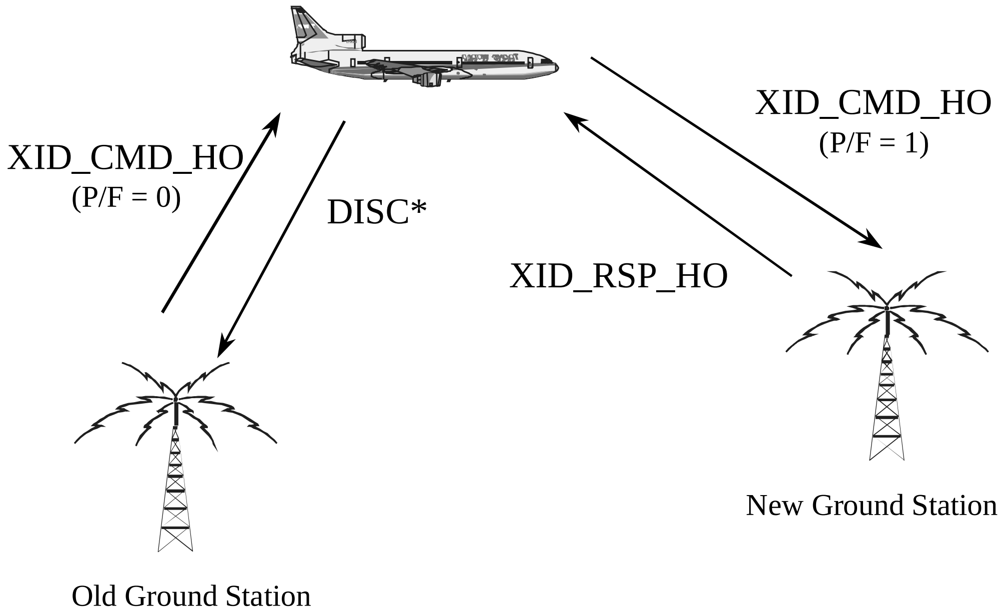

Figure 3-10 Ground Requested Aircraft Initiated Handoff

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 3.6-11 and Figure 3.6-12.

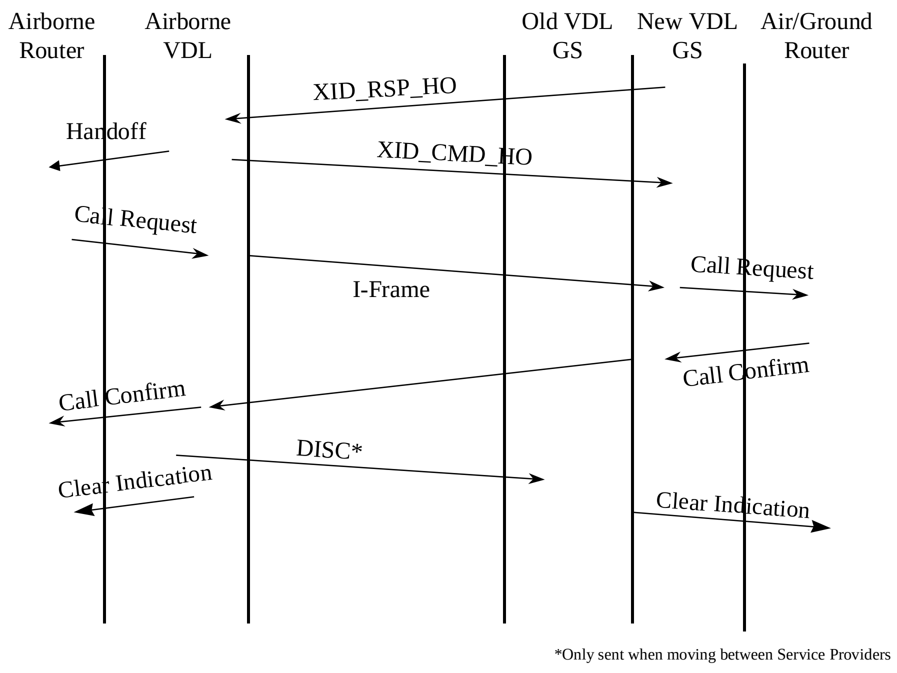

Figure 3.6-11 Explicit Subnetwork Connection Maintenance (Ground Initiated Handoff)

Note that with Ground Initiated Handoffs and expedited subnetwork connection maintenance, the Ground DTE is required to initiate the new calls (see Figure 3.6-12). 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 maintenance, it is still the aircraft that initiates the new virtual circuits.

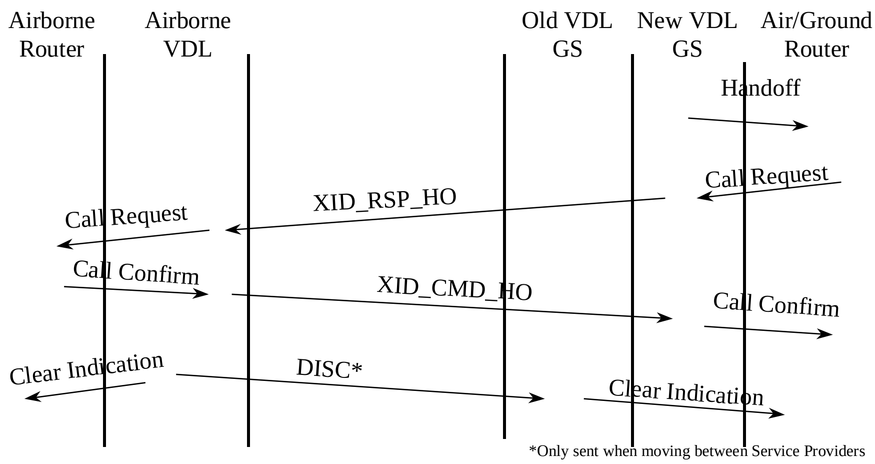

Figure 3.6-12 Expedited Subnetwork Connection Maintenance (Ground Initiated Handoff)

3.6.4.3.2.5 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.

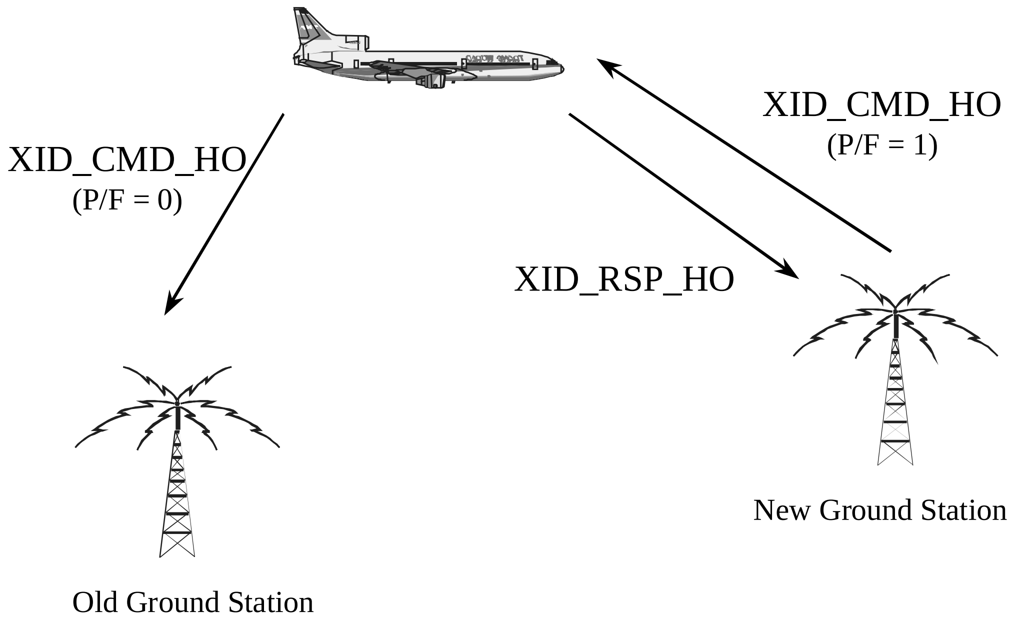

Figure 3.6-13 Aircraft Requested Ground Initiated Handoff

3.6.4.3.2.6 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.

The Ground Requested Broadcast Handoff 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.

3.6.4.3.3 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).

3.6.4.3.4 ATN Interconnection

3.6.4.3.4.1 Airborne Router

Logon to a new LME 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 a Handoff 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.

3.6.4.3.4.2 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.

However, as shown above in 3.6.4.3.2.4, when the expedited subnetwork connection maintenance procedures are used, the Handoff event is directed to the Air/Ground Router and this has, in this case, to initiate the establishment of the replacement virtual circuits.

3.6.4.3.4.2.1 Use of Compression algorithm

3.6.4.3.4.2.1.1 LREF compression

3.6.4.3.4.2.1.1.1 Use of the M/I bit procedure

Use of the LREF compression algorithm is mandated by the ATN Internet SARPs for all subnetworks. In the case of VDL, the M/I bit management procedure described in the ATN Internet SARPs must be used during VDL Handover.

3.6.4.3.4.2.1.1.2 LREF and Hand-offs procedure

With regard to the specification provided by the ATN Internet SARPs, it may happen that, during a VDL Handover, a packet requesting the creation of a directory entry is sent on the old virtual circuit, and subsequent packets for the same source/destination NSAPs are sent on the new virtual circuits in compressed mode. As VDL does not ensure that the packet sent on the old virtual circuit will be received by the adjacent router before the compressed one, compressed packets arriving first will be discarded and an error report is generated to the sending SNDCF.

In this case the transport protocol will eventually re-transmit the packet.

3.6.4.3.4.2.1.1.3 LREF and Call clearing

When the virtual circuit has been cleared for other reasons than as a result of Handoff and the LREF compression was used for the cleared virtual circuit, the internal resources used to handle the Local Reference Directory are released.

When the virtual circuit has been cleared due to Handoff and the maintenance bit was not set or refused for the newly established associated virtual circuit, the Local Reference Directory is released.

In all other circumstances the Local Reference Directory is maintained while subnetwork connections exist between the same pair of DTEs.

3.6.4.3.5 General VDL mode-3 characteristics

VDL Mode 3 provides both ATN data and digital voice services. VDL Mode 3 works by providing 4 logically independent channels in a 25 kHz frequency assignment. Each channel can be used for voice or data transfer. A design driver for VDL Mode 3 was the aim that a single radio should be able to provide voice and data services simultaneously.

There are eight configurations defined for VDL Mode 3. They offer a range of static voice and data channel assignments, as well as standard or long-range operation. One of the configurations provides dynamic channel assignment, in which a channel can be switched dynamically between voice and data.

VDL Mode 3 applies a concept of “user groups” which is a small number of users (maximum 60) that share slot(s). The concept is aimed at supporting sector operations with one controller and several aircraft in a single sector. A new mobile user to the system must join a user group before it can undertake data communications.

VDL Mode 3 digital voice offers some additional services compared to analogue R/T, for example, discrete voice addressing (in addition to voice broadcasts).

For data transmissions, all access is controlled from the ground. This means that if a mobile user wishes to transmit data it must request a transmission time from the ground station. The ground station will allocate the user a time based on the priority of the data and the other loading of the data link.

The sublayer functions are similar to VDL Modes 1 and 2 and are:

- The physical layer is based on the D8PSK at 31.5 kbps specification used for VDL Mode 2.

- The MAC sublayer uses a TDMA algorithm. This is more sophisticated than CSMA which is used in VDL Modes 1 and 2. The use of TDMA and a suitable control algorithm allows prioritisation of messages and controlled access to the data link.

- The DLS sublayer supports AVLC, which is a variant of the ISO HDLC protocol.

- The LME sublayer provides services to create and maintain link layer connections.

A voice module is added to provide analogue/digital conversion of voice signals.

Data Link Management procedures for Link Establishment and Handoff are expected to be the same as for VDL Modes 1 and 2.