APPENDIX D*

VDL IMPLEMENTATION ASPECTS

* This appendix is available in English only.

TABLE OF CONTENTS

Acronyms and Abbreviations

ABM	asynchronous balanced mode
ACK	acknowledge(ment)
ADM	asynchronous disconnected mode
A/G	air/ground
ATN	aeronautical telecommunication network
AVLC	aviation VHF link control
BCD	binary coded decimal
BER	bit error rate
CCIR	International Radio Consultative Committee
CMD	command (frame)
C/R	command/response (bit)
CSC	common signaling channel
CSMA	carrier sense multiple access
CW	continuous wave
D8PSK	differentially encoded 8 phase shift keying
DCE	data circuit-terminating equipment
DISC	disconnect (frame)
DLPDU	data link protocol data unit
DLS	data link service
DM	disconnected mode (frame)
DTE	data terminal equipment
DXE	denotes either: data terminal equipment, *or* data circuit-terminating equipment
FCS	frame check sequence
FEC	forward error correction
FRMR	frame reject (frame)
GI	group identification (field)
GSIF	ground station information frame
HDLC	high-level data link control
HIC	highest incoming channel
HO	handoff
HOC	highest outgoing channel
HTC	highest two-way channel
ICAO	International Civil Aviation Organization
ID	identification (identifier)
INFO	information (frame)
ISH	intermediate system hello (packet)
ISO	International Organization for Standardization

ITU-R	International Telecommunications Union - Radio Communication Sector
LCR	link connection refused
LIC	lowest incoming channel
LME	link management entity
LOC	lowest outgoing channel
lsb	least significant bit
LTC	lowest two-way channel
MAC	media access control
msb	most significant bit
MSC	message sequence chart
MSK	minimum shift keying
OSI	open systems interconnection
PDU	protocol data unit
P/F	poll/final (bit)
PN	pseudo noise
Q-bit	qualifier bit
REJ	reject (frame)
RF	radio frequency
RNR	receive not ready (frame)
RR	receive ready (frame)
RSP	response (frame)
RVC	redirected virtual circuit
SARPs	Standards and Recommended Practices
SDL	specification and description language
SDU	service data unit
SNAcP	subnetwork access protocol
SNPA	subnetwork point of attachment
SNPDU	subnetwork protocol data unit
SNR	signal to noise ratio
SNSAP	subnetwork service access point
SQP	signal quality parameter
UA	unnumbered acknowledgment (frame)
UI	unnumbered information (frame)
VDL	VHF digital link
VHF	very high frequency
XID	exchange ID (frame)
XOR	exclusive OR

SECTION 1 - DEFINITIONS AND SYSTEM CAPABILITIES

1. Definitions and system capabilities

1.1 **Background**. The very high frequency (VHF) digital link (VDL) communications system is one of a number of aircraft-to-ground subnetworks that may be used to support data communications across the aeronautical telecommunication network (ATN) between aircraft-based application processes and their ground-based peer processes. The data communications functions, in turn, are supported by the digital communication protocols employed by the VHF data transceiver and supporting avionics of the VDL system.

1.2 **Compatibility**. The international aviation community is expected to adhere to the separation of communication functions as specified in the open systems interconnection (OSI) reference model developed by the International Organization of Standardization (ISO). The OSI Reference Model permits the development of open communications protocols as a layered architecture comprising seven functional separate layers. VDL communications functions are compatible with the open systems interconnection (OSI) model for data communications and constitute the first step toward a fully OSI-compatible protocol stack. The VDL system will provide code transparent communications between ATN comformant systems. Specifically, they are performed by the lower three layers of the OSI model: the physical layer, the data link layer, and the lowest sub-layer of the network layer (i.e. the subnetwork layer). The following figure presents the VDL system within the ATN protocol architecture:

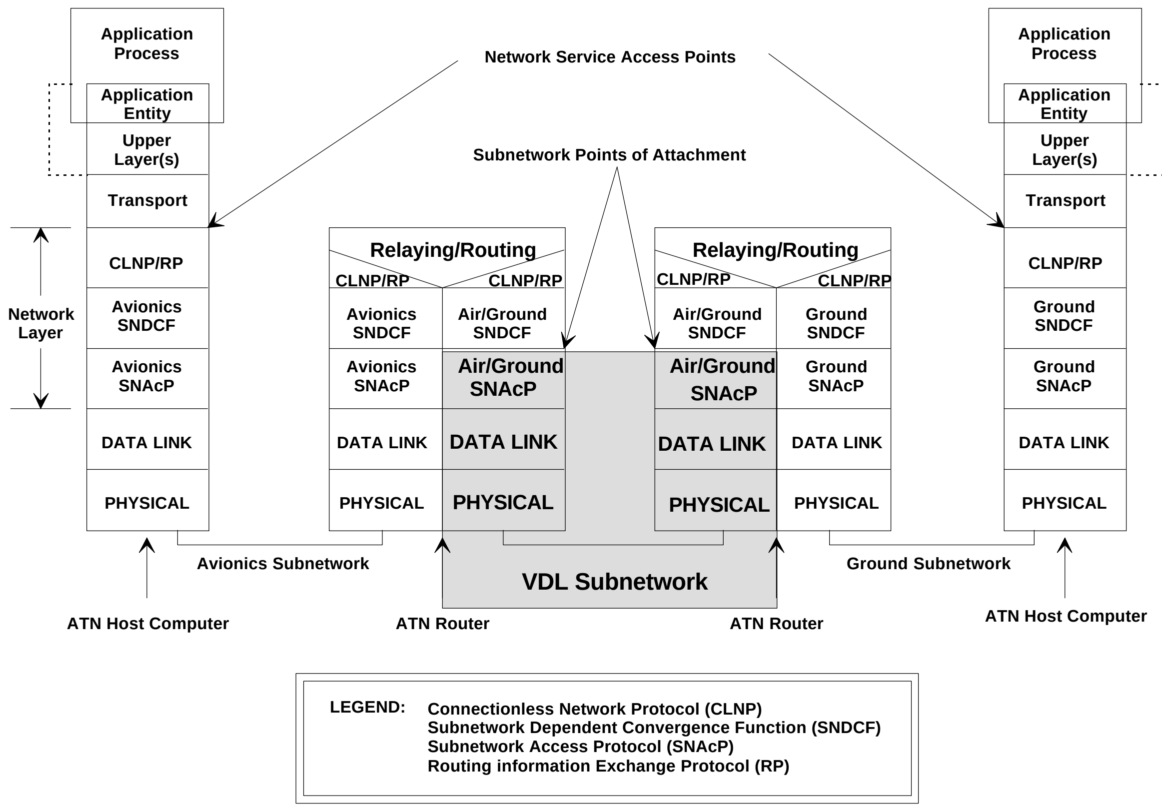


Figure 1-1. ATN protocol architecture

1.3 **General architecture**. In the absence of operational requirements, the VDL Design Guidelines were developed to be used as a baseline document for the VDL system design and as an interface control document for other working groups and panels.

1.3.1 The VDL system is based on the OSI Reference Model and, therefore, has been designed in a modular fashion which separates the functions of the physical, data link and the lower sub-layer of the network layers. There are two different modulation schemes, or modes, that have been defined for the VDL physical layer each of which can interoperate with the upper layers without affecting the protocol stack.

1.3.2 The aviation VHF link control (AVLC) layer comforms to the high-level data link control as specified by ISO 3309, ISO 4335, ISO 7809 and ISO 8885. However, given HDLC was design to primarily support stationary network terminals where bandwidth for the most part is not scarce, the AVLC has been optimized to take into account the fact that the VDL network terminals are in a mobile environment with limited bandwidth available. The VDL subnetwork layer protocol used across the VHF A/G subnetwork comforms to ISO 8208.

1.3.3 **Ground infrastructure options**. In principle, the VDL SARPs should in no way restrict the ability to chose a particular VDL ground infrastructure based on the specific requirements of the ICAO Contracting States and various telecommunication institutions. The following scenarios may describe the situation in each State:

a) *VDL and ATN network operated by CAA* − only CAA-operated VDL ground stations, connected to CAA router(s), to provide at least ATS communications (ATSC);

b) *VDL and ATN network operated by commercial services provider* − only ground stations operated by commercial services provider, to support aeronautical operational communication (AOC) and, if so, required by the local CAA, even ATSC through the service provider router, which may be located in a different State;

c) *VDL network and ATN network operated by both commercial services provider and CAA* − ground stations providing both AOC and ATSC, simultaneously connected to an AOC router (outside the State) and to a CAA router (within the country), in order to save capital expenditures (especially at beginning of transition) and spectrum; and,

d) *VDL and ATN network operated by both commercial services provider and CAA* − CAA ground stations (for ATSC) and commercial service provider ground stations (for AOC), operating within the same designated operational coverage.

1.4 **Interoperability**. The VDL communications functions will provide subnetwork services so that interoperability among subnetworks can be maintained. Interoperability allows an application process to send or to receive data messages over any of the available subnetworks without having to select a particular subnetwork or to know which subnetwork is being used for a particular message. These other subnetworks might include, but are not limited to aeronautical mobile-satellite (route) service (AMS(R)S) and Mode S data link.

1.5 **Subnetwork selection**. The choice of the specific subnetwork to be used is a function of the quality-of-service (QOS) requested by the application, the QOS of the available subnetworks, and the specific user and network provider policies.

1.6 **Frequency management**. Frequency management is a co-operative effort between the ground network and the aircraft. Ground service providers dynamically assign operational frequencies within a particular airspace to resolve factors beyond the control of the aircraft. The resulting system is able to adjust frequencies freely to account for designated operational coverage (DOC), air traffic control (ATC) sector boundaries, ATN administration domains, and local traffic conditions.

1.7 **Common signalling channel**. The designation of a common signaling channel (CSC) provides a ready means for an aircraft first to log on to the system. When coverage exists in an area, it will always exist at least on the CSC. Once a connection is established on the CSC, an aircraft can be retuned to any discrete frequency within the assigned frequency range. The CSC also may be utilized as a common channel, when there is an emergency, or as a default channel whenever communication is lost; when traffic is light in an area, it may be used as a normal data channel.

1.8 **Naming convention.** The following leading identifiers are used to identify with which protocol sub-layer a primitive or protocol entity is associated:

Protocol sub-layer	*Single-letter identifier*	*Two-letter identifier*
Physical layer	P	PH
Media access control sub-layer	M	MA
Data link sub-layer	D	DL
Link management entity sub-layer	G	LM
Subnetwork layer	S	SN

1.8.1 **Sub-layer relationship.** Figure 1-2 shows the relationship between the sub-layers, including the primitives which flow between the sub-layers. The primitives outlined in Figure 1-2 are also outlined at the end of this document in the form of message sequence charts (MSC) which depict the sequence of events for the key VDL processes such as:

a) VHF subnetwork initiation process (explicit subnetwork connection);

b) VHF subnetwork explicit subnetwork handoff;

c) VHF subnetwork expedited subnetwork handoff; and

d) VHF subnetwork termination process.

1.9 **External interfaces.** The external interfaces to the VDL are noted by connections between a module and the containing box. The leading identifier of the connection names the missing entity.

Protocol sub-layer	*Identifier*
Subnetwork dependent convergence facility	N
Broadcast subnetwork dependent convergence facility	B
Internetworking services system management entity	IS
Exceptions processing entity	E
Radio frequency	RF

Figure 1-2. Primitive flow diagram

SECTION 2 - PHYSICAL LAYER PROTOCOLS AND SERVICES

2. Physical layer protocols and services

The physical layer provides services to activate, maintain, and de-activate connections for bit transmission in the data link layers. The following service elements are the responsibility of layer 1:

a) activation of the transmission channel;

b) establishment of bit synchronization;

c) physical data transmission by an appropriate radio system;

d) channel status signalling;

e) fault condition notification;

f) local network definitions; and

g) service quality parameters

2.1 **Introduction**. Data link layer user data is passed to the physical layer on primitives. Data link user data received by the physical layer entity from a remote physical layer entity via the VHF media is passed up to the data link layer on a primitive. Any indications required for diagnostic or error conditions are passed between these layers on service primitives.

2.2 Functions

2.2.1 **Transceiver control**. Frequency selection will be performed upon requests passed on from the link layer. Transmitter keying will be performed on demand from the data link layer to transmit a frame.

2.2.2 **Notification services**. Signal quality indication will be performed on the demodulator evaluation process using parameters such as phase distortion, coherence, and signal-to-noise measurements and on the receive evaluation process using parameters such as signal strength, carrier detect, and output power.

2.3 **Interface to peer entities**. Two different modulation schemes have been defined for the VDL. MSK (Mode 1) has been included as a backwards compatible mode, consistent with existing VHF analogue radios. D8PSK (Mode 2) has been defined to increase throughput. The large gain in information bandwidth of D8PSK (11.2 dB greater than MSK) occurs for little change in link margin because the double sideband-amplitude modulation (DSB-AM) loss factor has been eliminated (8.0 dB at 80 per cent modulation depth).

2.3.1 Transmission characteristics for Mode 1

2.3.1.1 **Mode 1 modulation**.

Text to be added here.

2.3.2 **Transmission characteristics for Mode 2**

2.3.2.1 **Mode 2 modulation**. D8PSK may be produced by combining by two quadrature RF signals which are independently suppressed carrier amplitude modulated by baseband filtered impulses. The baseband impulse filters have a frequency response with the shape of a raised cosine with an excess bandwidth factor equal to 0.6. This characteristic allows a high degree of suppression of adjacent channel energy, with performance dependent only upon hardware implementation of the modulating and amplification circuits.

2.3.2.1.1 **Multi-phase encoding**. The Mode 2 modulation scheme will use the Gray Coding method to map or assign the *3 bit* information bits into one of the eight (8) possible phases. Gray Coding is one in which adjacent phases differ by one binary digit as illustrated in the figure below:

The most likely errors caused by noise involve the erroneous selection of an adjacent phase to the transmitted signal phase and by using the Gray Coding method only a single bit error occurs in the three (3) bit sequence.

2.3.2.1.2 **Mode 2 rate**. Future modes of VDL that incorporate TDMA access schemes may employ the baseband symbol clock to maintain timing for media access. In this case, it is expected that ground equipment supporting TDMA access scheme will require a tolerence in the baseband symbol clock of at least ±.001%.

2.3.2.2 **Forward error correction**. The systematic, lightweight Reed-Solomon code selected is simple to code and can be decoded with progressively more complicated decoding techniques as shown by Table 2-1.

Table 2-1. FEC coding gain

Decoding technique	*Coding gain*	*Complexity*
none	0 dB	trivial to skip code bits
hard-decision	1.5 dB	COTS chipsets to perform decoding algorithm available
soft-decision	4 dB	CPU power required to perform decoding not feasible with 1994 technology

2.3.2.3 **Example encoded message**. Messages are encoded as the example in Figure 2-3, which corresponds to the following text.

Figure 2-3. Message encoding block diagram

Text to be added here.

2.3.2.4 **Training sequence for Mode 2**

2.3.2.4.1 **Unique word**. In an environment with an E_b/N_0 of 13 dB (a BER of 10^{-3}), a synchronizer using sixteen samples per symbol and a desired probability of false alarm of 10^{-10} will have a probability of missed synchronization of 10^{-8}.

2.3.2.4.2 **Header FEC**. The block code is capable of correcting all 1-bit errors and detecting, but not correcting, about 25 per cent of the possible 2-bit errors.

2.3.3 **Channel sense algorithms**. When running a CSMA algorithm prior to transmitting data or packetized voice, the VDL receiver can determine if the channel is idle by using an energy sensing algorithm. However, because the local noise floor is not a constant, an estimator is needed. This section provides an example of one possible estimator.

Note.− The MAC sub-layer declares the channel idle after the channel sense algorithm reports that the received signal power level has crossed below the busy threshold.

2.3.3.1 **Channel quiescent value**. Whenever the VDL is not transmitting or receiving a message, the VDL calculates a channel quiescent value, T_b, according to the following algorithm:

where

L is the rms received signal level in hard µvolts calculated over the preceding 1 ms;
T_{max} is a value in the range of 15 to 30 hard µvolts; (exact calibration is not necessary);
$T_q[n]$ is the estimate of the noise floor at time n;

and

Note.- The non-linear function k(·) is designed to quickly adjust to a reduced noise level and to slowly adjust to an increased level.

2.3.3.2 **Channel busy threshold**. The channel busy threshold, T_b, is defined as 1.4 T_q. The channel is declared idle until the rms received signal value, L, exceeds T_b. Then the channel is declared busy and the channel sense algorithm is suspended while synchronization is attempted.

2.3.3.3 **Synchronization**. If synchronization is not achieved (i.e. the unique word is not detected) within the times stated in Table 2-2, then a new value is taken for the rms received signal level, L, and processed to yield the channel quiescent value, T_q, and the channel sense determination.

Table 2-2. Synchronization times

Mode	*Synchronization timeout*
1	40 ms
2	2.5 ms

2.3.3.4 **Receiver/transmitter interactions**

Figure 2-4. Turnaround time requirements

Note.- The attack and delay characteristics are not shown to scale.

2.4 **Physical layer system parameters**. The maximum transmission length that a receiver is capable of demodulating without degradation of BER for Mode 1 and Mode 2 is 15 485 bits and 131 071 bits respectively.

$P1_{Mode\ 1}$ = [(maximum number of bits in any frame) x (random expected increase because of bit stuffing) + (eight bits for the terminating flags of each frame)] x (the maximum number of frames in a transmission) + (eight bits for the start flag)

$$= [2168 \times (63/62) + 8] \times 7 + 8 = 15\ 485 \text{ bits}$$

$P1_{Mode\ 2} = [2^{17} - 1] = 131\ 071$ bits

The Mode 2 transmission length is more that the maximum transmission length of seven (7) frames and it only applies to the ground system which can uplink frames to more than one aircraft in one transmission.

2.5 Interface to upper layers. Primitives associated with the VDL are as detailed in Sections 2.5.1 through 2.5.6.

2.5.1 **Data**. The PH_DATA primitives are passed between the DLS sub-layer and the physical layer to transfer user information between entities. The following primitives are associated with this service:

PH_DATA.request
PH_DATA.indication

2.5.1.1 **Request**. PH_DATA.request is the service request primitive for the data transfer service. This primitive is generated by the DLS sub-layer and passed to the physical layer to request user data transmission. The receipt of this primitive by the physical layer causes the physical layer to transmit user data.

Parameters: User data parameter (M) (contains physical layer service data unit [SDU]).

2.5.1.2 **Indication**. PH_DATA.indication is the service indication primitive for the data transfer service. This primitive is generated by the physical layer and passed to the DLS/LLC-1 sub-layer to transfer received user data.

Parameters: User data parameter (M) (contains physical layer SDU).

2.5.2 **Change frequency and mode**. PH_FREQ.request is the service request primitive for the frequency request service. This primitive is generated by the LME sub-layer and passed to the physical layer. The receipt of this primitive by the physical layer causes the local physical layer to select the VHF frequency and mode requested by the PH_User.

Parameters: Desired frequency (M)
Desired mode (M)

2.5.3 **Channel sense**. The following primitives are passed from the physical layer to the MAC sub-layer to support the CSMA algorithm:

PH_BUSY.indication
PH_IDLE.indication

2.5.3.1 **Busy**. PH_BUSY.indication is the service indication primitive for the busy detection service. This primitive is generated by the physical layer and passed to the MAC sub-layer whenever the channel transitions from idle to busy.

2.5.3.2 **Idle**. PH_IDLE.indication is the service indication primitive for the idle detection service. This primitive is generated by the physical layer and passed to the MAC sub-layer whenever the channel transitions from busy to idle.

2.5.4 **Signal quality**. PH_SQP.indication is the service indication primitive for the signal quality service. This primitive is generated by the physical layer and passed to the LME sub-layer to indicate the signal quality of the current transmission. This primitive is generated usually once per received transmission and applies to the entire transmission.

Parameters: Signal quality parameter (M)
Source station address parameter (M)

2.5.5 **Peer address**. PH_ADD.indication is the service indication primitive from the LME sub-layer to the physical layer to indicate the link address of a peer station. The physical layer will use this information to filter and route the incoming frames to the appropriate DLS entity. This primitive is generated whenever a link is establish or disconnected.

Parameters: Source station address parameter (M)
Source station related DLS process ID (M)

Note.- A process ID of null will indicate that the associated link has been disconnected.

2.5.6 **Channel occupancy**. PH_OCC.indication is the service indication primitive for channel occupancy service. This primitive is generated by the physical layer and passed to the DLS/LLC /LME to indicate the channel occupancy which will be use to compute the retransmission interval. This primitive is generated periodically with a value between 0 and 1.

The following is an example of one CU calculation approach that can be used:

CU can be calculated in the transceiver by sampling the channel to determine occupancy every 1 second averaged over the past 100 seconds. CU can range in value from 0 to 1 with 1 corresponding to a channel that is 100 percent occupied. The channel is considered to be occupied if either the transceiver or another station is determined to be transmitting at the time the sample is taken.

Parameters: Channel Occupancy (M)

2.6 **Interface to physical processes**. Primitives associated with the VDL are as detailed in Sections 2.6.1 through 2.6.4.

2.6.1 **Data**. The RF_PDU primitives are passed between the physical layer and the physical processes to transfer user information between entities. The following primitives are associated with this service:

RF_PDU.xmt
RF_PDU.rcv

2.6.1.1 **Transmit**. RF_PDU.transmit is the service transmit primitive for the data transfer service. This primitive is generated by the physical layer to transmit user data.

Parameters: User data parameter (M)

2.6.1.2 **Receive**. RF_PDU.receive is the service receive primitive for the data transfer service. This primitive is received by the physical layer when receiving data.

Parameters: User data parameter (M)

2.6.2 **Channel sense**. The RF primitives are passed between the channel occupied detection algorithms and the physical layer to indicate the current state of the RF transmission media. The following primitives are associated with this service:

RF_BUSY.indication
RF_IDLE.indication
RF_OCC.indication

2.6.2.1 **Busy**. RF_BUSY.indication is the service busy indication primitive for the channel sensing service. This primitive is received by the physical layer when the channel becomes occupied.

2.6.2.2 **Idle**. RF_IDLE.indication is the service idle indication primitive for the channel sensing service. This primitive is received by the physical layer when the channel becomes idle.

2.6.2.3 **Channel occupancy**. RF_OCC.indication is the service idle indication primitive for the channel occupancy service. This primitive is received by the physical layer and is an measurement of the channel occupancy.

2.7 **SDL description**. The SDL description for the physical layer is in Figure 1-2.

2.8 **States**. The physical layer is stateless, and has no real state.

SECTION 3 - LINK LAYER PROTOCOLS AND SERVICES

3. Link layer protocols and services

3.1 **General information**. The link layer is responsible for transferring information from one network entity to another, for annunciating errors encountered during transmission, and for providing the following services:

a) assembly and disassembly of frames;

b) establishment of frame synchronization;

c) rejection of nonstandard frames;

d) detection and control of frame errors;

e) selection of RF channels;

f) recognition of addresses;

g) initiation of receiver muting; and

h) generation of the frame check sequence.

The link layer provides the basic bit transmission service over the RF channel. Data at the link layer is transmitted as a bit stream in a series of frames exchanged between the aircraft transceiver and the ground-based radio elements.

3.2 Media access control (MAC) sub-layer

3.2.1 MAC functions

3.2.1.1 **P-Persistent CSMA**. While the channel is idle, a station with a packet to send transmits with probability p, and waits for TM1 seconds before trying again with probability 1 - p. If the channel becomes busy during the wait, the TM1 timer is cleared and the system again waits for the transmission to terminate.

3.2.1.2 **Maximum wait time**. In order to ensure a finite wait time, a maximum number of access attempts will be made. For a given value of p and the desired cumulative probability, v, M1 can be computed by M1 = [log(1 - v) / log(1 - p)]. The default values for M1 have been chosen so that v = 0.999, or that 99.9 per cent of all transmissions will occur before M1 attempts have been made.

3.2.1.3 **Inter-access delay**. The value of TM1 is set to the duration between when one station decides to transmit and every other station can detect that transmission. Therefore, this value is constructed by summing the receive-transmit turnaround time, the transmitter attack time, the maximum propagation delay time, and the idle-busy channel sense detect time.

3.2.1.4 **Timers.** Table 3-1 summarizes the timers used in the MAC sub-layer.

Table 3-1. MAC sub-layer timers

Timer	*Started*	*Cancelled or restarted*	*Action upon expiration*
TM1	By random backoff algorithm after access failure	Cancelled when channel becomes busy	Attempt to gain access to the channel
TM2	On request to transmit	Cancelled upon transmission	Begin frequency recovery LME function

Figure 3-1. MAC process

Figure 3-1 provides an overview of the VDL MAC timers as well as the MAC processes which are executed when a station is attempting to access the VHF channel.

3.2.2 **Interface to the upper layers.** The primitives defined for the MAC layer are detailed in Sections 3.2.2.1 to 3.2.2.2. Note that primitives to control MAC parameters negotiable via XIDs are not included.

3.2.2.1 **Transmission authorization**. Two primitives are passed between the MAC sub-layer and the DLS sub-layer to support the transmission of frames.

MA_RTS.request
MA_CTS.indication

3.2.2.1.1 **Request to send**. MA_RTS.request is the service request primitive for the transmission authorization service. This primitive is generated by the DLS sub-layer and passed to the MAC sub-layer to request permission to activate the physical transmission channel.

3.2.2.1.2 **Clear to send**. MA_CTS.indication is the service indication primitive for the transmission authorization service. This primitive is generated by the MAC sub-layer and passed to the DLS sub-layer to grant authorization for a single transmission.

3.2.2.2 **Channel congestion**. One primitive is used by the channel congestion service to indicate that the channel has become congested and that recovery mechanisms should be invoked.

MA_EVENT_TM2.indication

3.2.2.2.1 **Busy channel indication**. The MA_EVENT_TM2.indication is the service primitive for the channel congestion service. This primitive is sent by the MAC sub-layer to the DLS and LLC-1 sub-layer when the TM2 timer expires indicating a busy channel.

3.2.3 **SDL description**. The SDL description for the MAC sub-layer is in Figure 1-2.

3.2.3.1 **States**. There are four states in the MAC sub-layer and are shown in Figure 3-2.

3.2.3.1.1 **Idle**. The MAC sub-layer is in the **idle** state when the RF channel is clear and there are no outstanding requests to transmit.

3.2.3.1.2 **Busy**. The MAC sub-layer is in the **busy** state when the RF channel is busy and there are no outstanding requests to transmit.

3.2.3.1.3 **Pending**. The MAC sub-layer is in the **pending** state when the RF channel is clear and there are outstanding requests to transmit.

3.2.3.1.4 **Waiting**. The MAC sub-layer is in the **waiting** state when the RF channel is busy and there are outstanding requests to transmit.

Figure 3-2. MAC State diagram

3.3 Data link sub-layer (DLS)

3.3.1 Architecture

The data link entities (DLE), which provide connection-oriented point-to-point links with peer DLE's, exist within the data link sub-layer (DLS). The DLE in effect is the data link state machine which implements the aviation VHF link control (AVLC) protocol (i.e. connection-oriented and connection-less functions) as well as the transmit queue functions.

The link management entity (LME), which acquires, establishes and maintains a link connection with its peer LME, exists within the VHF management entity (VME). One VME exists for each airborne and ground system. Figure 3-3 provides an overview of the data link layer with its related sub-layers and entities.

Figure 3-3. Data link layer Overview

A ground system is composed of, but not limited to, VHF ground stations, a ground network providing connectivity with the ATN routers, and a VME which manages the VDL aircraft having link connections with the ground system. The ground VME will create one (1) LME for every aircraft that is "logged-on" to the VDL ground system and similarly, the airborne VME will create one (1) LME for each ground system that it communicating with. These peer LMEs will use the information provided by the received XID's (ex. lat/long position parameter, airport destination, acceptable alternate ground stations, etc.).and other information sources (ex. transceiver's signal quality/strength of received frames) to establish and maintain reliable links between the aircraft and the VDL ground system.

In the example below (Figure 3-4), the two aircraft have each one link with the same ground station which also supports broadcast services. The station LLC-1 entity also exists within the respective DLS and is responsible for processing the connection-less datagrams received from a peer broadcast entity.

In a one ground system scenario (i.e. the aircraft is in the coverage area of one VDL data link service provider) the aircraft station will have at most two (2) active DLEs at any one time. This will only occur when the aircraft is in the process of performing a handoff between the existing ground station and a new ground station. The handoff procedures are outlined in section 3.4.1.4.

Figure 3-4. DLS sub-layer architecture

Figure 3-5 provides a system overview of the VME, LME and DLS concept by using an aircraft which has link connections with two different VDL ground systems. The ground infrastructure depicted below may viewed that link #1 using service provider #1 provides concurrent subnetwork connectivity to both an ATC and AOC routers, where as link #2 over service provider #2 provides subnetwork connectivity to only one router.

Figure 3-5. System overview of VME, LME and DLS

Using the example in Figure 3-5, in order to support this ground infrastructure the following link management entities have been created in the airborne and ground systems:

*Number of **VMEs***	airborne: 1 ground: 1 each (total of 2)
Comments: The airborne and ground systems have only VME to management all VDL links.	

*Number of **LMEs***	airborne: 2 ground: 1 each (total of 2)
Comments: Two LMEs exists within the airborne VME and have been created to manage the VDL Link #1 and #2. Subsequently, ground systems #1 and #2 have also created one LME each to control and manage this aircraft.	

Number of ***DLEs***	airborne: 2 ground: 1 each (total of 2)
Comments: For each LME there exists one DLE (except during handoffs). Airborne DLE #1 and #2 support the AVLC protocol with ground DLEs #1 and #2. Ground DLE#1 exists within the ground station which the aircraft has established a link (ground system #1). Similarly, ground DLE#2 exists within the ground station which the aircraft has established a link (ground system #2).	
Total Number of Switched Virtual Circuits (SVCs)	Between Airborne DTE and ground ATN routers: 3
Comments: There are two subnetwork connections established between the airborne DTE and the ATN routers 1A and 1B over the pair of DLE #1. In addition, there is one subnetwork connection residing over the pair of DLE #2 which provides a subnetwork connection between the aircraft and the ATN router 2.	

3.3.2 **Functions**

3.3.2.1 **Retransmission algorithm**. The link layer uses an adaptive retransmission algorithm. This algorithm is comprised of two elements: measuring the transmission delay (which can be used to determine the minimum retransmission time) and an exponential backoff (which provides damping when the channel becomes congested and reduces the effects of miscomputed transmission delay measurements).

3.3.2.1.1 **Transmission delay measurement**. The transmission delay is measured from two input events: the channel utilization measurement provided by the physical layer (which will be used to calculate the 99 per cent percentile of successfully accessing the channel) and the time to receive an acknowledgment for an unretransmitted frame (i.e. the time for the peer entity to access the channel). This algorithm, based on the algorithm used in TCP/IP, uses two registers to compute a likely upper bound for the transmission delay, avg_est (estimate of the average) and mdev_est (estimate of the mean deviation). Note that avg_est and mdev_est are scaled versions of the actual values, and that only integer computations are needed. The C code for the algorithm is as follows:

```
measurement -= (avg_est >> 3);
avg_est += measurement;
if ( measurement < 0)
measurement = -measurement;
measurement -= (mdev_est >> 2);
mdev_est += measurement;
trans_delay = ((avg_est >> 2) + mdev_est) >> 1;
```

Note.− This algorithm is documented in Jacobson, Van, "Congestion Avoidance and Control", ACM Sigcomm '88, August 1988, pages 314-329. Mean deviation is used instead of the standard deviation because it is much quicker to compute, but gives very similar results.

3.3.2.2 **Acknowledgment process and transmission queue management.** In order to improve the VDL acknowledgement process as well as to minimize the retransmission period which ultimately affects the protocol recovery period, special considerations where given to the frame rejection and T1 timer processes.

3.3.2.3 In VDL, multi-selective reject (SREJ) option is used, however the format and SREJ process have departed from the standard HDLC protocol. The following is a summary of these changes:

SREJ Format	• bit 1 of the control field (in the Information portion) will be set to 1 to indicate frames (identified in bits 6-8) that have been correctly received by the peer DLE (i.e. deviation for the standard HDLC protocol), and set to 0 to indicate frames that need to be retransmitted (i.e. same process as in the standard HDLC protocol)
SREJ Process	• the P bit will always be set to 0 except when T4 expires or when checkpoint procedures have been invoked by the peer DLE. A SREJ with P bit set to 0 will indicate that all frames N(r)-1 have been acknowledged. • SREJ (P = 0) will not be retransmitted after T1 expiration if there is no explicit response from the peer DLE (i.e. the peer DLE will end-up retransmitting all outstanding frames after the T1 expiration). The SREJ (P = 1) will be retransmitted only upon T1 expiration.

3.3.2.4 In order to reduce the protocol recovery period, the T1 timer is reset based on the time of the oldest queued frame and not based on the current time. In addition, only those frames that have been queued (i.e. DLE entity has passed the frames to the transmission queue for transmission) for at least T1min + 2TD will be retransmitted upon T1 expiration. In this manner, frames will not be re-queued prematurely without providing the peer station sufficient time to respond. Figure 3-6 outlines three examples of the SREJ and T1 processes.

Figure 3-6. SREJ and T1 flow diagrams

3.3.2.5 **FRMR/UA process.** The FRMR frame is always sent as a command frame with the P/F bit set and is meant to signal the resetting of the link in situations where a reset may be necessary to resolve a transitory problem. The following situations will cause an FRMR frame to be issued:

a) a frame with a bad or unknown control field;

b) a frame with an invalid size;

c) a frame with an invalid acknowledgement number;

d) a frame received with an invalid C/R bit and/or P/F bit combination, for instance, a UA frame received as a command, or, a response frame with the P/F bit set when we are not expecting a response frame;

e) a T1 timeout when the station is in FRMR mode; and

f) an information frame or XID frame that is more than N1 bytes in length.

Note.– Frames without control fields and frames with unknown addresses are ignored.

Three bytes of information will follow the AVLC header. These bytes will correspond, as per ISO 4335, to the information fields of an FRMR frame in modulo 8 operation. Bits w,x,y and z will be coded as per ISO 4335.

The sender of the FRMR frame will remain in the reset state until a UA frame response frame is received back from the remote, or a DISC frame is received from the remote station which would result in the termination of the link as well as the associated packet level entity.

3.3.2.6 **TEST frame process.** The TEST command will be used to cause the addressed station to respond at the first respond opportunity. An information field is optional with the TEST command however, if present the receiving information field will be returned in the TEST response. The TEST frame process can be executed by any station in any operational or non-operational state. For example, even if the aircraft has not executed an link establishment with a ground system, a ground station transmitting a TEST command will expect a response from that aircraft. The TEST command will have no effect on the mode or sequence variables maintained by the transmitting and responding stations.

3.3.2.7 **SABM/UA frame process.** The SABM command is not used in VDL because the link is established by the exchange of XID_CMD and XID_RSP frames.

3.3.3 Interface to the peer entity

3.3.3.1 **Addresses**. The current address space allows a single radio address per aircraft. Each ground station radio should have a different address so that radios on different frequencies which are attached to the same ground station will have different addresses. This is done to mitigate the effect of RF spurs and intermodulation products which corrupts peer entity contact table (PECT) maintenance (see LME section for use of the PECT). The combination of spurs and intermods will occasionally cause a station to be intelligible on other frequencies. The use of different addresses for different frequencies can reduce the problem.

3.3.3.1.1 **Air/ground status bit**. The air/ground status bit should be set by all aircraft which have that information available. This bit may be used by service providers to decide whether to retune an aircraft and to which frequency it should be retuned, during takeoff and landing.

3.3.3.1.2 **Command/response status bit**. Normal ISO 4335 procedures use the address field to disambiguate command and response frames. However, in a broadcast media this procedure does not work properly, consequently an explicit bit is used to specify the type of frame.

3.3.3.1.3 Data link service parameters

3.3.3.1.3.1 **N1 Computation.** The N1 parameter (i.e.maximum number of bits in any frame) is computed as follows:

Mode 1 (min): N1 = [11 (link layer) + 4 (packet layer) +128] x 8 = 1144

Mode 1 (default): N1 = [11 (link layer) + 4 (packet layer) +256] x 8 = 2168

Mode 2 (default): N1 = [11 (link layer) + 4 (packet layer) +1024] x 8 = 8312

Mode 2 (Max): N1 = [11 (link layer) + 4 (packet layer) +2048] x 8 = 16504

As per ISO standards, the flag is not counted in the above calculations.

3.3.3.1.3.2 **T2 Parameter.** The VDL station that receives a frame which requires a response, has be able to process this frame within T2 time. That is, if the MAC p value is set to 1 and there is no other traffic on the channel, then the VDL station has to produce a transmission within the T2 interval.

3.3.3.2 **Receive not ready (RNR)**. The standard HDLC frame to denote a temporary inability to communicate, the RNR PDU, is not used in AVLC. This is primarily because sending an RNR requires a second frame to clear the condition. It is more efficient to occasionally ignore a frame or two, and the potential for large outages while trying to clear the RNR condition is avoided.

3.3.3.3 **Timers**. Table 3-2 gives a quick summary of the operation of the DLS sub-layer timers.

Table 3-2. DLS sub-layer timers

Timer	*Started*	*Cancelled or restarted*	*Action upon expiration*
T1	Upon queuing a frame to the transmit queue, and when T1 timer not running	Cancelled upon receipt of an acknowledgement.	Retransmit frames which have been enqueued for at least T1min +2TD.
T3	Upon queuing XID_CMD to the transmit queue.	Cancelled upon receipt of XID_RSP	Retransmit XID_CMD
T4	Upon receipt of any frame	Restarted upon receipt of any frame	Send an RR command (P = 1) or FRMR (P=1) or SREJ (P=1) depending on the state, for up to N2 times

3.3.3.3.1 **Values prior to link establishment**. Prior to establishing a link with a ground station, an aircraft should use the default values for the MAC and DLS parameters unless a GSIF setting new values is received from the ground station with which the aircraft is attempting to establish a link.

3.3.4 **Interface to the upper layers**. ISO 8886, *Data Link Service Definition for Open Systems Interconnection*, is the basis for the DLS sub-layer design. This service definition has extra primitives to resolve that exposed interface.

3.3.4.1 **Data transfer**. Two primitives are passed between the DLS sub-layer and the subnetwork layer to support the connection-oriented transfer of data. This is an unconfirmed service.

DL_DATA.request.
DL_DATA.indication.

3.3.4.1.1 **Request**. DL_DATA.request is the service request primitive for the connection-oriented transfer of data. This primitive is generated by the subnetwork layer and passed to the DLS sub-layer to request the transfer of data over a specific link.

Parameters: Link ID (M)
User data (M)

3.3.4.1.2 **Indication**. DL_DATA.indication is the service indication primitive for the connection-oriented transfer of data. This primitive is generated by the DLS sub-layer and passed to the subnetwork layer to indicate the receipt of valid data over a specific link.

Parameters: Link ID (M)
User data (M)

3.3.4.2 **Unitdata transfer**. Two primitives are passed between the LLC_1 sub-layer and the network layer to support the connection-less transfer of data. This is an unconfirmed service.

DL_UNITDATA.request.
DL_UNITDATA.indication.

3.3.4.2.1 **Request**. DL_UNITDATA.request is the service request primitive for the connection-less transfer of data. This primitive is generated by the network layer and passed to the LLC_1 sub-layer to request the broadcast transfer of data.

Parameters: Destination address (M)
User unitdata (M)

3.3.4.2.2 **Indication**. DL_UNITDATA.indication is the service indication primitive for the connection-less transfer of data. This primitive is generated by the LLC_1 sub-layer and passed to the network layer to indicate the receipt of valid broadcast data.

Parameters: Source address (M)
User unitdata (M)

3.3.4.3 **XID transfer**. Two primitives are passed between the LLC_1 sub-layer and the LME sub-layer to support the transfer of XIDs. This is an unconfirmed service.

DL_XID.request.
DL_XID.indication.

3.3.4.3.1 **Request**. DL_XID.request is the service request primitive for the transfer of XIDs. This primitive is generated by the LME sub-layer and passed to the DLS sub-layer to request the transfer of an XID to a specific address.

Parameters: Destination address (M)
Link ID (O)

3.3.4.3.2 **Indication**. DL_XID.indication is the service indication primitive for the transfer of XIDs. This primitive is generated by the DLS sub-layer and passed to the LME sub-layer to indicate the receipt of valid XID from a specified address.

Parameters: Source address (M)

3.3.4.4 **DM transfer**. Two primitives are passed between the LLC_1 sub-layer and the LME sub-layer to support the transfer of DM frames. This is an unconfirmed service.

DL_DM.request.
DL_DM.indication.

3.3.4.4.1 **Request**. DL_DM.request is the service request primitive for the transfer of a DM frame. This primitive is generated by the LME sub-layer and passed to the LLC 1 sub-layer to request the transfer of an DM frame to a specific address.

Parameters: Destination address (M)
Link ID (O)

3.3.4.4.2 **Indication**. DL_DM.indication is the service indication primitive for the transfer of received DM frames, unicasted frame except for an XID, that are not associated with any existing links. This primitive is generated by the LLC 1 sub-layer and passed to the LME sub-layer indicating the source address.

Parameters: Source address (M)

3.3.4.5 **State management**. Two primitives are passed between the DLS sub-layer and the LME sub-layer to support the link maintenance service.

DL_BLOCK.request
DL_UNBLOCK.request

3.3.4.5.1 **Block**. DL_BLOCK.request is the service request primitive for the link outage service. This primitive is passed from the LME sub-layer to the DLS sub-layer when a link is temporarily unavailable and the LME sub-layer is attempting to restore it. The receipt of this primitive informs the DLS sub-layer that a remote entity is temporarily unavailable for the transfer of data.

Parameters: Link ID (M)

3.3.4.5.2 **Unblock**. DL_UNBLOCK.request is the service request primitive for the link operational service. This primitive is passed from the LME sub-layer to the DLS sub-layer when a link is viable. The receipt of this primitive informs the DLS sub-layer that a remote entity is available for the transfer of data. If the new address is 0, then a quiet disconnect (delete the entity and all associated information, but do not send a DISC) should occur.

Parameters: Link ID (M)
Address (M)

3.3.4.6 **Reset**. Three primitives are passed from the DLS/LLC_1 sub-layer to the LME sub-layer in the provider initiated reset service.

DL_RESET_N2.indication
DL_RESET_TM2.indication
DL_RESET_FRMR.indication

3.3.4.6.1 **No response**. DL_RESET_N2.indication is the service indication primitive for a no response. This primitive is passed from the DLS or LLC-1 sub-layers to the LME sub-layer when no response is received from a remote entity. The receipt of this primitive causes the LME sub-layer to initiate site recovery procedures.

Parameter: Link ID (M)

3.3.4.6.2 **Congested channel**. DL_RESET_TM2.indication is the service indication primitive for a congested channel caused provider initiated reset. This primitive is passed from the DLS or LLC-1 sub-layer to the LME sub-layer when the channel is detected as congested. The receipt of this primitive causes the LME sub-layer to initiate frequency recovery procedures, hopefully shielding the upper layers from the temporary loss of service.

3.3.4.6.3 **Protocol error**. DL_RESET_FRMR.indication is the service indication primitive for a protocol error caused provider initiated reset. This primitive is passed from the DLS sub-layer to the LME sub-layer when a protocol error is detected either in the local or remote DLS sub-layer. The receipt of this primitive informs the LME sub-layer that the link is cleared, and that upper layer data may have been lost.

Parameter: Link ID (M)]
Cause (O)

3.3.4.7 **Disconnect**. Either LME sub-layer (ground or avionics) can initiate a disconnect. Disconnection is not subject to the response of a higher layer, but is treated as an automatic sequence once initiated. The primitives associated with the connection termination service are:

DL_DISC.request
DL_DISC.indication

3.3.4.7.1 **Request**. DL_DISC.request is the service request primitive for the connection termination service. This primitive is generated by the LME sub-layer and passed to the DLS sub-layer when the LME sub-layer wishes to terminate a connection. Receipt of this primitive causes the DLS sub-layer to immediately terminate the specified link.

Parameter: Link ID (M)
Reason (O)

3.3.4.7.2 **Indication**. DL_DISC.indication is the service indication primitive for the connection termination service. This primitive is generated by the DLS sub-layer and passed to the LME sub-layer to signal an immediate disconnect. Receipt of this primitive means that the LME sub-layer may no longer use this link.

Parameter: Link ID (M)
Reason (M)

3.3.5 **SDL description**. The SDL description of the DLS sub-layer is in Figures 1-2.

3.3.5.1 **States**. There are five states in the DLS state machine, with one entity per connection. A state diagram of the DLS sublalyer is outlined in Figure 3-7.

3.3.5.1.1 **Idle**. The DLS entity is in the disconnected mode. It can accept an XID from the remote DLS entity or generate an XID to initiate a link based on a request from the local LME sub-layer.

3.3.5.1.2 **Data transfer ready**. A data link connection exists between the local DLS entity and the remote DLS entity. Sending and receiving of information and supervisory PDUs can be performed.

3.3.5.1.3 **Blocked**. A data link connection exists between the local DLS entity and the remote DLS entity. However, sending of information and supervisory PDUs cannot be performed until some temporary loss of service is resolved. Note that receiving of PDUs is still possible.

3.3.5.1.4 **FRMR state**. A data link connection exists between the local DLS entity and the remote DLS entity. However, sending of information and supervisory PDUs cannot be performed until a UA frame is received or a DISC frame which would result in the termination of the link.

3.3.5.1.5 **Disconnect state**. A data link connection has been disconnected between the local DLS entity and the remote DLS entity, and the local DLS is waiting for the LME to kill this instance of the DLS process.

Figure 3-7. DLE State Diagram

3.3.6 DLS test scripts

A set of airborne and ground system DLS test scripts have been developed to guide the implementation of the respective DLEs. These test scripts are outlined at the end of this document.

3.4 Link management entity

3.4.1 Functions

3.4.1.1 **Initialization**. The system management entity should start operation of the LME. The LME is then responsible for establishing a link layer connection. This could occur by either use of acommon signaling channel or by a frequency search function.

Note.− The system management entity is an ATN entity which is beyond the scope of this document and which controls the operation of the router and the subnetwork selection algorithm.

3.4.1.2 **Common signaling channel**. The common signaling channel (CSC) (136.975 MHz) is used wherever service providers what to announciate the VDL availability of CNS services over VHF carriers using the Mode 2 physical MAC layers (i.e. D8PSK and CSMA). By guaranteeing one common frequency, the problem of the aircraft in trying to locate a valid frequency is minimized. Also, aircraft tuned to frequencies other than the CSC do not need the frequency list XID parameter to be aware of an alternate frequency to use in the frequency recovery function.

3.4.1.2.1 **Invocation**. The LME should use the CSC to establish a link level connection when commanded startup or other search algorithms have failed, and an aircraft is equipped for Mode 2, and is in a service area that offers Mode 2. The aircraft LME tunes the radio to the CSC and attempts to establish a link. After a link is established, the ground station may send an autotune command to the aircraft to have it switch to a different frequency.

3.4.1.2.2 **Failure**. If no link can be established using the CSC, then the LME may optionally use the frequency search function. Otherwise, the CSC function remains active.

3.4.1.3 **Frequency search**. The frequency search function attempts to establish a data link connection with any station on any frequency. Frequencies known *a priori* to be available for data service are scanned, and upon detection of an appropriate/usable signal, a link is established.

3.4.1.3.1 **Invocation**. The LME should perform the frequency search function upon commanded startup or failure of other search algorithms, and either the aircraft cannot use Mode 2, or is not in a service area that offers Mode 2 service.

3.4.1.3.2 **Failure**. If the frequency search function fails, the LME may use the CSC, or remain in the frequency search function.

3.4.1.3.3 **Timer TG1 (maximum frequency dwell time)**. This timer is implementation-dependent and is included as an example of what parameter(s) an implementation may include in the frequency search table. The frequency search table is a static table located in the aircraft LME which lists possible frequencies on which to attempt to make a link, the provider(s) available on that frequency, and whatever other pertinent information is required by the specific LME implementation in the selection of an optimal frequency.

3.4.1.4 **Idle peer detection**. There are two timers, T4 and TG2, which are used by the VDL to detect an idle/missing peer entity. In the aircraft, TG2 is set relatively short (to a multiple of TG3) and is reset when the ground station transmits to any aircraft. This allows an aircraft to quickly detect when a ground station cannot be received (either because the aircraft is no longer with range of the ground station or the ground station failed). The airborne T4 timer is used as a minimum traffic generator so that the ground system can determine that the aircraft is still around. The ground T4 timer is used to detect when an aircraft has departed from the region. However, the ground TG2 timer is set much longer, so that basic information about the location of the aircraft will survive even though the link is torn down and the resources used elsewhere.

3.4.1.5 **Link establishment**. When the airborne LME establishes a link layer connection with the ground system, it will inform the SNDCF or the IS-SME of the ATN router NETs information received and the link ID for the new link. The SNDCF will indicate this link ID in all CALL REQUEST primitives which apply to that link.

Note.− The link identifier will differentiate between two state machines in the same radio and two state machines in different radios.

3.4.1.6 **Timers**. Table 3-3 gives a brief summary of the timers in the LME sub-layer.

Table 3-3. Link management entity timers

Timer	*Started*	*Cancelled or restarted*	*Action upon expiration*
TG1 (aircraft only)	Initially tuning to a frequency during frequency search	Receiving any uplink on frequency	Retune to new frequency in frequency search table
TG2	Upon receipt of transmission from a station.	Restarted upon receipt of transmission from a station.	Remove entry from PECT; if link exists with that entity, perform recovery operation.
TG3 (ground only)	Upon tx of any frame	Restarted upon tx of any frame	Transmit a GSIF
TG4 (ground only)	Upon tx of any GSIF	Restarted upon tx of any GSIF	Transmit a GSIF
TG5 (air only)	Opening a second link with a ground station operator	Should never be restarted	Consider old link disconnected

3.4.2 Interface to the peer entity

3.4.2.1 Exchange identity (XID) format

An XID frame may consist of public parameters, private parameters and user data. The public and private parameters used in XIDs frames and are listed in the VDL SARPs tables 3-37a, b and c. The group identifiers in this document are encoded in the reverse manner to ISO 8885.

3.4.2.1.1 **Handoff request**. The process by which a ground station requests an aircraft to initiate a ground station change (e.g. an autotune to a new frequency) involves the exchange of three XIDs between the ground system and the aircraft. The ground system will continue to retransmit the XID_CMD_HO (P = 0) on the old frequency, until the XID_CMD_HO (P = 1) from the aircraft is received on the new frequency to resolve a lost XID_CMD_HO (P = 0). The aircraft will continue to transmit the XID_CMD_HO (P = 1) on the new frequency until the XID_RSP_HO (P = 1) from the ground system is received to resolve a lost XID_CMD_HO (P = 1). This uses the minimum number of frames to ensure a reliable handoff. This process has been generalized where one entity wants the other to begin the handoff process.

3.4.2.1.2 **Ground station information frames**. Ground stations will periodically transmit ground station information frames broadcasting certain information for the aircrafts' LMEs to use. (The GSIFs are broadcast in a randomized window so that two transmitters hidden from each other will not synchronize and always collide.)

3.4.2.1.2.1 **Destination airport identifier**. The GSIF identifies the airport at which the ground station is located or, if the ground station is not located at an airport, the airport closest to the ground station is identified. An aircraft may, at its discretion, choose to connect to the station located at the flight's destination, so that the number of ground station changes is minimized and so that the aircraft does not suddenly drop below the radio horizon of the ground station while it is descending.

3.4.2.1.2.2 **Supported facilities**. The GSIF identifies all frequencies and protocols that the ground station supports. The aircraft LME stores this information to be used when trying to contact the stations during ground station changes. This allows the LME to re-tune the radio and know information about ground stations on that frequency without having to wait for several GSIFs to be transmitted. All GSIF transmissions will also include the HDLC and AVLC options parameters to also factor into any handoff decisions. When an aircraft establishes a link with the ground system, it will provide a list of the facilities that it supports. The ground system LME stores this information to be used when deciding what type of service to provide the aircraft.

3.4.2.1.2.3 **Operational parameters**. The service provider operating the ground station is responsible for management of the channel. It may become necessary for the ground service provider to adjust certain parameters throughout the area for better over-all throughput on the channel. For channel management, the GSIF may broadcast new values of MAC persistence, M1, TM2, T4, TG5, k, and N2 for use by all aircraft connected to it. After the ground transmits an XID_RSP_LE to establish a link with an aircraft, a GSIF may be transmitted to set the operational parameters for that aircraft. The operational parameters are usually transmitted in a GSIF, so that all aircraft in the vicinity may receive the update.

3.4.2.1.2.4 **Ground station location**. All GSIF transmissions will include either the airport identifier or the nearest airport identifier.

3.4.2.1.3 **Ground to air connection-oriented XID parameters**. The ground-air connection-oriented XID transmissions contain various parameters used for maintaining the link.

3.4.2.1.3.1 **Mandatory parameters**. All connection-oriented XID frames will include the XID sequencing parameter. Connection-oriented XID frames will include the connection management parameter when establishing, or handing over a link.

3.4.2.1.3.2 **Connection management**. The connection management parameter identifies the type and function of the XID. This parameter is not included in GSIFs or when operational parameters are being modified without resetting connection. For instance, an XID exchange to change the protocol options in use would not include the connection management parameter.

3.4.2.1.3.3 **Autotune**. The autotune frequency parameter allows the ground station to manage multiple frequencies in a congested area. The ground station may request that an aircraft re-tune to a different frequency and initiate link establishment on the new frequency. The replacement ground station parameter will be included to inform the aircraft of which ground station to attempt to contact. The new ground station may belong to a different service provider.

Note.− In order to properly implement make-before-break across two frequencies, the aircraft will need two VDL radios.

3.4.2.1.3.4 **Replacement ground station**. The replacement ground station parameter can be used without the autotune parameter when the ground station are on the same frequency.

3.4.2.1.4 **Air to ground connection-oriented XID parameters**. The air-ground connection-oriented XIDs contain various parameters concerning the link.

3.4.2.1.4.1 **Mandatory parameters**. All connection-oriented XID frames will include the XID sequencing parameter. Connection-oriented XID frames will include the connection management parameter when establishing, or handing over a link.

3.4.2.1.4.2 **Connection management**. The connection management parameter identifies the type and function of the XID. This parameter is not included in GSIFs or when operational parameters are being modified without affecting the connection. For instance, an XID exchange to change the protocol options in use would not include the connection management parameter.

3.4.2.1.4.3 **Handoff**. In general, the aircraft LME will monitor the SQP values of all transmissions from ground stations. When it determines that a ground station change is needed, it will send an XID to the selected (new) ground station. It may include a list of alternate (acceptable) ground stations. The ground service provider may, at its discretion, reply from another ground station (usually in the alternate list). This allows, among other functions, a means of load-balancing the ground stations.

3.4.2.1.4.4 **Destination airport**. The flight's destination airport is transmitted so that the ground service provider may use that information in selecting the ground station from which to send a reply.

3.4.2.1.4.5 **Supported facilities**. When first establishing a link, the aircraft informs the service provider of modulation schemes it is capable of supporting so that the service provider may use this information when performing frequency management. The connection-establishment XID may also include the HDLC and AVLC protocol options parameter.

3.4.2.1.4.6 **SQP measurement transfer**. Ground-air and air-ground XID frames may include the SQP parameter of the other station's last received transmission. This is expected to be used for testing purposes only.

3.4.3 Interface to the upper layer

3.4.3.1 **Link availability**. Four primitives are passed between the LME and the system management entities (SME) and the VHF-SNDCF entity for the link availability service.

LM_STARTUP.request
LM_SHUTDOWN.request
LM_LINKUP.indication
LM_LINKDOWN.indication

3.4.3.1.1 **Startup**. LM_STARTUP.request is the primitive passed from the aircraft SME to the LME to request that a VDL link be set up. The receipt of this primitive causes the aircraft LME to begin attempting to establish a link with a ground link layer entity.

3.4.3.1.2 **Shut down**. LM_SHUTDOWN.request is the primitive passed from the SME to the LME to request that the VDL link shut down. The receipt of this primitive causes the LME to disconnect all currently established links and go to a halt state.

3.4.3.1.3 **Link up**. LINKUP.indication is the primitive passed from the LME to the SNDCF to indicate that the VDL link is available. The receipt of this primitive causes routing initiation procedures to be invoked.

Parameters: ATN router NETs (M)
Link ID (M)

3.4.3.1.4 **Link down**. LINKDOWN.indication is the primitive passed from the LME to the SNDCF to indicate that the VDL link is currently unavailable. The receipt of this primitive causes routing termination procedures to be invoked.

Parameters: Link ID (M)

Note.– additional LME primitives are outlined in section 5 of this document.

3.5 LME Test Scripts

A set of airborne and ground system LME test scripts have been developed to guide the implementation of the respective LMEs. These test scripts are outlined at the end of this document.

SECTION 4 - SUBNETWORK LAYER PROTOCOLS AND SERVICES

4. Subnetwork layer protocols and services

4.1 **Architecture**. When a received frame passes through the link layer, the layer 2 header and trailer used for processing are stripped off. The remaining data link service (DLS) user_data parameter is passed within a DLS primitive up to the subnetwork layer. This remainder is a subnetwork protocol data unit (SNPDU) or, informally, a **packet**.

4.2 **Functions**. The subnetwork layer is responsible for controlling the data packet flow with respect to duplicate, lost, or invalid packets. Data passing through the subnetwork layer for transmission is broken into segments, called SNPDUs, for control and error recovery.

The basic service of the subnetwork layer is to provide for the transfer of data across the subnetwork. The subnetwork protocol is responsible for internal routing and relay functions across the subnetwork, which are outside the scope of the level 1 and level 2 routing, as defined in the *ISO/IEC TR9575: 1990 (E) OSI Routing Framework*.

4.3 **Interface to peer entities**

4.3.1 **Acknowledgment window**. Because typical 8208 implementations generate an RR for every data packet, the acknowledgment process has been modified by creating an explicit acknowledgment window and by replacing almost all timer-based functions with event-based functions, thereby reducing the load on the RF channel. By setting the window wider than one, the probability of an explicit acknowledgment is reduced (with A = 7, an RR is sent around 1 per cent of the time).

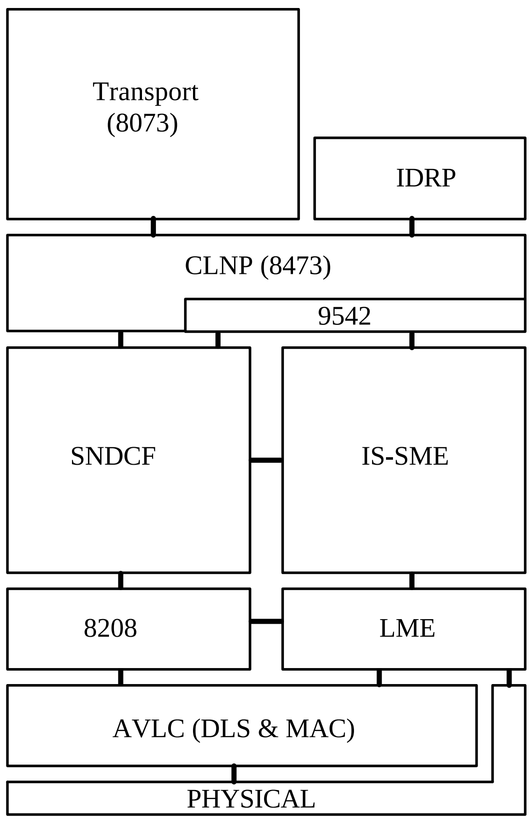
4.3.2 **Packet size**. By modifying P and W, the packet size and transmit window size parameters, the system can control the amount of outstanding information, and consequently the delay a packet in the network layer queue will experience.

4.4 **Interface to upper layer**. ISO 8348, *network service definition*, includes detailed definitions of the primitives interfacing with the upper layer.

SECTION 5 - VDL SUBNETWORK CONNECTION MANAGEMENT

5. VDL subnetwork connection management

The ATN Internet protocols consist of the Internetworking Protocol (ISO 8473) as well as other protocols such as Inter-domain Routing Protocol (IDRP - ISO 10747) and ES-IS routing exchange protocol (ISO 9542). Given VDL is a connection-mode Subnetwork Access protocol (SNAcP), an SNDCF (Subnetwork Dependent Convergence Facility) is required to provide a transparent Connection-less mode service to the ATN internetworking protocol. The VDL protocol stack as well as the associated ATN stack is shown below:



The VDL subnetwork consists of an airborne subsystem and a network of remote ground stations (RGS). The predominantly line-of-sight nature of VHF radio limits its use for air/ground communications to airspace that can be served by ground based stations. The airborne subsystem functions as a mobile communication terminal, establishing and re-establishing link and subnetwork connections with ground stations that can provide reliable connectivity with ground DTEs (or Air/Ground routers). An aircraft enroute to its final destination will be required to re-establish connections (handovers) with numerous ground stations as the aircraft moves from one RGS coverage area to another. In view of these VHF characteristics, the VDL subnetwork initiation, handover and termination processes must be tailored appropriately as to minimize the communication exchanges over the RF but at the same time provide a global baseline for the different implementation envisioned by the different States, Airlines and Service Providers (SP).

5.1 VDL subnetwork connection management overview

The VHF subnetwork connection management is primarily comprised of three phases:

a) connection initiation;

b) connection hand-off (or handover); and

c) connection termination

Connection Initiation

As per the VDL SARPs, the airborne VDL entity is responsible for initiating the link and subnetwork connection(s) with available VDL ground systems upon service start-up. The VHF airborne initiation mechanism is comprised of the following processes:

a) a frequency search and acquisition process;

b) a link establishment and parameter setting process; and

d) a subnetwork establishment process.

The frequency search and acquisition is performed with the aid of the common signaling channel (CSC), the link establishment and parameter setting process is performed with the exchange of XID frames and the subnetwork establishment process is performed with the exchange of 8208 CALL packets.

Connection Handoff

As the aircraft moves from one remote ground station (RGS) coverage region to another, handoffs will be required to maintain VDL communications. The airborne LME may wish to handoff (depending on signal quality, policy based, etc.) to a new RGS that may or may not have access to the same A/G router as the current RGS.

The connection handoff process comprises of the following phases:

1. link re-establishment and parameter setting process
2. expedited or explicit subnetwork establishment process

The VDL protocol provides a subnetwork maintenance facility that permits an aircraft to handoff from one RGS to another, without requiring the re-initialization of the "ATN contexts" (i.e. IDRP/SNDCF Local Reference Table) if both RGSs have access to the same ground DTE (i.e. air/ground router). This handoff process is be executed by using the standard 8208 CALL procedures each time the airborne entity changes ground stations, but depending if the peer systems support expedited subnetwork connections, these CALL establishment packets will be part of the XID frames or will be send as INFO frames (standard method). The expedited and implicit handover processes are outlined in detail below

Connection Termination

VDL connection termination may be initiated by either the airborne or ground entities. Some of the reasons for the airborne system terminating VDL connections are loss of VDL ground coverage, unrecoverable error or the VDL ground service is no longer needed.

5.2 VDL System Management Entities

5.2.1 Link Management Entity (LME)

The functions of the LME are:

- ground station identification
- aircraft frequency search
- initial link establishment and parameter negotiation
- link parameter modification
- aircraft and ground initiated ground station handovers

The Ground Station Identification Frames (GSIFs) are transmitted periodically by the VDL ground stations as to inform any aircraft (i.e. airborne LME) the existence as well as the operational parameters of the sending ground station. The LME may also use any uplink traffic from the ground stations to update its Peer Entity Connection Table (PECT) which is used by the aircraft to initiate air/ground link connections and handovers.

A Common Signaling Channel has been reserved to facilitate the LME frequency acquisition process. All Ground Station Service Providers that are offering VDL services in a particular region will identify themselves (via GSIFs) on this channel. Included in the GSIF or Autotune XID frames will be the VDL frequency that an airborne user may tune its VHF transceiver to access the necessary service. If more than one ground station Service Provider are supporting VDL services in a particular region, it then becomes an higher layer (i.e. IS-SME) policy matter to who's ground network the aircraft will establish a connection with. These policies are dictated by the respective user. The LME and the associated primitives are shown in Table 5-1.

5.2.2 Subnetwork – system management entity (SN-SME)

The SN-SME's main role is to generate events which advertise a change in the subnetwork connectivity. The SN-SME will trigger the LME to initiate the frequency acquisition process under certain conditions (ex. avionics equipment power-up). At the same token, the SN-SME will also shut-down the VHF service triggered by external events such as the termination of a flight.

5.2.3 Intermediate system – system management entity (IS-SME)

As per the *Manual of the Aeronautical Telecommunication Network (ATN)* (Doc 9578), a series of system management actions triggered by events will be used to establish and terminate communications between boundary intermediate systems (BIS). The intermediate system management entity (IS-SME) is located in all the air/ground and airborne routers. Its main role is to trigger the ISO 9542 ES-IS protocol for the ISH PDU transfer (peer discovery process), and to start-up the ISO 10747 Routing Protocol.

The LME will pass to the IS-SME all the necessary information derived from the GSIFs and available VDL traffic, so that the IS-SME can determine which service is available to support the on-board applications. In the content of the GSIFs or XID connection management response frames, the VDL ground station will indicate the partial network entity titles (NETs) (i.e. ADM and ARS fields) of the air/ground routers that are accessible to the aircraft. Primarily there will be two category of router: AOC and ATC. If a RGS indicates that it has accessibility to both ATC and AOC routers, the aircraft may decide to establish two subnetwork connections to each A/G router for the exchange of AOC and ATC traffic respectively. The IS-SME will be responsible for making the decision to which ground DTE a subnetwork connection is required to support the Internetworking protocol as well as the on-board applications.

For an airborne DTE to establish a subnetwork connection with a ground DTE (i.e. air/ground router), it requires a subnetwork point of attachment (SNPA). The VDL specification supports both specific VDL addresses and X.121 addresses as SNPAs. VDL specific addresses are coded addresses which reflect the desired SNPA of the air/ground ATN router that the airborne DTE wishes to establish a subnetwork connection with. As outlined above, the GSIFs will contain the partial NETs of the accessible A/G routers, and depending on their transmitted order in the GSIF frame, a VDL specific DTE address can be derived. In addition, the ground station provider may also support exact addressing, that is, X.121 formatted DTE addresses. The IS-SME is responsible for the SNPA resolution process and for initiating the Call process with the VHF-SNDCF. The IS-SME and its associated primitives are shown in Table 5-1.

5.2.4 VHF system management entity messages

Please refer for Figure 1-2 which outlines the relationship between the sub-layers, including the primitives which are outlined below.

Table 5-1. System Management Entity Messages

From	To	Message/Primitive	Information Conveyed
External Agents	IS-SME	ATC_Control APPS_Request	• indicates the transfer of tactical control to the next ATC/FIR center • on-board applications informing of their A/G communications requirements
External Agents	SN-SME	VHF_SERVICEup.req VHF_SERVICEdown.req	• request the initiation of a VDL subnetwork service (ex. avionics power-up or at flight initiation) • request the termination of the VDL subnetwork service (ex. flight termination)
SN-SME	LME	LM_STARTUP.req LM_SHUTDOWN.req	• activation of LME (i.e. frequency acquisition, ground station identification etc.) • de-activation of LME and associated air/ground link connections
IS-SME	LME	LM_SERVICE_startup.req LM_SERVICE_shutdown.req	• requesting the LME to establish link connection with the specified service (provided by LM_SVCS_AVAIL.ind) • requesting the LME to tear-down an existing link with a service
IS-SME	VHF-SNDCF	SC_SNPA.req	• specification of the SNPA to be used when constructing the Call request packet (i.e. X.121 or VDL specific addresses)
IS-SME	ES-IS	IS_LINKUP.ind	• triggering event for the peer discovery mechanism (i.e. ISH PDU)
LME	IS-SME	LM_SVCS_AVAIL.ind	• list of Services available (i.e. high speed/low speed VDL Service, VDL Service Providers, accessible routers, VDL RGS operating parameters, etc.)

LME	VHF-SNDCF	LM_LINKUP.ind LM_LINKDOWN.ind LM_NOEXP_CALL.ind LM_EXP_CALL.ind LM_SUBNET.ind	• indication that the link has been successfully established with the requested service (from LM_SERVICE_startup.req). • indication that the link has been broken for a specified reason. • indication that the ground system does not support expedited handoffs. • indication that the ground system does support expedited handoffs. • in the case of a expedited subnetwork establishment, these primitive will forward the CALL REQUEST or CALL CONFIRMATION packet to the VHF-SNDCF that was included in the XID frame.
VHF-SNDCF	LME	LM_SUBNET.req	• in the case of a expedited subnetwork establishment, these primitive will forward the CALL REQUEST or CALL CONFIRMATION packet to the LME so that is can be include in the XID frame.

VHF-SNDCF	IS-SME	SC_LINKUP.ind SC_SNPAup.ind SC_SNPAdown.ind SC_NOEXP_CALL.ind	• indication that the link (i.e. first time) has been successfully established and a subnetwork connection may be initiated at this point. • confirmation that a subnetwork connection (i.e. SNPA) has been successfully established or handed-over (expedited or explicit). • indication that a subnetwork connection (i.e. SNPA) has been torn-down for a particular reason. • indication that an explicit handover is required (i.e. construction of CALL REQUEST) because the ground system does not support expedited subnetwork handoffs.

5.3 VDL Subnetwork Initiation Process

As mentioned above, the VHF initiation process is comprised of a frequency search and acquisition process, a link establishment and parameter setting process and subnetwork establishment process. The message sequence chart (MSC) for the VHF Subnetwork initiation process is shown at the end of this section.

5.3.1 Frequency acquisition and determination of available services

At VHF service start-up (i.e. SN_SME commanded), the LME will tune the VDR to the CSC (PH FREQ.req) in order to discover the available VDL services together with their associated frequencies. The type of services available in a particular region can span from one ground station provider connected to only one A/G router, to multiple ground station providers connected to multiple routers with different operating parameters (i.e. low speed, high speed, RVCs, ATC routers, AOC routers). The annunciation of the services will be done by the RGSs via the periodic transmission of GSIFs.

The LME will use the GSIFs and uplink traffic (DL_XID.ind and PH_SQP.ind) to update its PECT. The LME will not only keep track of the type of services available but also the ground stations that these services are available by. It will take a maximum of TG1 time for the LME to acquire all the available services broadcasted on the CSC.

5.3.2 Link establishment

The LME will inform the IS-SME of the type of services available in the particular region (LM_SVCS_AVAIL.ind). The IS-SME will have prior knowledge of the airborne applications requiring A/G communications (via the APPS_Request primitive) and will request the LME to establish a link connection with the appropriate service (LM_SERVICE_startup.req). For example, the airline may have AOC data to send to their central Host such as engine monitoring reports in which the IS-SME will request the LME to establish a connection with their preferred ground station provider who is able to deliver this type traffic to the airline's end-system.

The required service may not be available on the CSC and therefore before the LME can initiate the link establishment and parameter setting process it will have to re-tune the VDR to the appropriate service frequency (the broadcasted GSIF on the CSC will enunciate among other things the VHF service frequencies).

If the aircraft and ground system does not support expedited subnetwork connections, the airborne LME will exchange XID frames as outlined in the VDL SARPs as part of the link establishment process (DL_XID.req and DL_XID.ind). Once the LME has successfully completed the link establishment and parameter negotiation processes, it will inform the VHF-SNDCF that a subnetwork connection can be initiated at this point (LM_LINKUP.ind). (The example given at the end of this section assumes that expedited subnetwork connections are not supported).

5.3.3 Subnetwork establishment and routing initiation

Once a link connection has been established with a VDL ground station, the IS-SME is responsible for triggering the subnetwork connection as well as the peer discovery processes.

The VHF-SNDCF will require a SNPA and the intermediate system hello protocol data unit (ISH PDU) to construct the CALL REQUEST packet to be sent to the ground DTE (i.e. A/G router) which can provide ATN connectivity to the desired end-system. As mentioned above, the VDL protocol supports both VDL specific and exact addressing. The IS-SME will determine which ground DTE to establish a subnetwork connection and thereafter convey the appropriate SNPA to the VHF-SNDCF (SC_SNPA.req). Moreover, as part of the peer discovery process the ISH PDU will be included in the CALL REQUEST packet as part of the call user data field. The IS-SME will trigger the ES-IS entity to send the ISH PDU to the VHF-SNDCF in order to complete the construction of the CALL REQUEST packet (SC_ISH_PDU.req).

The 9542 process will pass the ISH PDU as well as the maintained/initialized bit set to 1 found in the SNDCF parameter block as per the VDL and ATN SARPs to the VHF-SNDCF. The VHF-SNDCF will build the CALL REQUEST packet, by placing the SNPA provided by the IS-SME in the *Called Address* field if the SNPA is an exact address, or will place the VDL specific address in the *Called Address Extension* facility and then placing ISH PDU provided by the 9542 process in the *User Data* field using the *Fast Select* 8208 facility. The *Calling Address* field will include the aircraft 24-bit address.

The VHF-SNDCF will then pass this CALL REQUEST packet to the 8208 entity for transmission over the link and physical layers (SN_CALL.req).

The A/G router will accept the call by generating a *CALL ACCEPT* packet including:

the ISH PDU as part of the user data field identifying the A/G router's NET
the SNDCF parameter block, indicating that the router cannot maintain subnetwork connections

Note.– it is assumed that this is the first subnetwork connection that the A/G router has with this aircraft.

Once the aircraft receives the CALL ACCEPT packet from the called A/G router, the VHF-SNDCF will convey this information to the ES-IS entity and will inform the IS-SME that the subnetwork connection has been successfully completed (SC_SNPAup.ind). The 9542 process will then:

a) activate the forwarding information base (FIB); and

b) initiate the IDRP process which is responsible for the exchange of routing information between the two entities.

The airborne IDRP entity will then generate the appropriate OPEN and UPDATE PDUs with its peer entity.

5.3.4 VDL Handoff Process

The handover scenario that will be covered in this section is a handoff from one VDL RGS to another which have accessibility to the **same** A/G router. The case of a handoff from one VDL RGS to another which do not have accessibility to the same A/G router is similar to the subnetwork initiation process outlined in section 5.3.3 and will not be covered in this section.

As mentioned above, the VDL protocol supports both an *expedited* and *implicit* handoffs for subnetwork connection maintenance. The VDL Handoff MSCs are shown at the end of this section.

Explicit Handoff Protocol Overview

If an aircraft DTE wishes to *explicitly* request a subnetwork connection to a ground DTE, it will send a CALL REQUEST packet to the ground DTE with the fast select user data field containing the ISO 9542 ISH PDU, after link establishment.

Expedited Subnetwork Handoff Protocol Overview

If the ground system supports expedited subnetwork connection handoffs, the aircraft can include in the XID handoff frame the CALL REQUEST packet and thus reducing the number of transmissions over the RF.

5.3.5 VHF Explicit Handoff Process

In order for subnetwork connections to be maintained across ground station changes, the aircraft LME will give preference in choosing a new ground station to a ground station indicating accessibility to the DTEs to which subnetwork connections already exist. In this manner the type of "service" will remain the same and it will require minimum intervention by the IS-SME. The MSC for the explicit handover case is shown at the end of this section.

Depending on the signal quality of the existing link relative to the signal quality of other neighboring ground stations, the LME will initiate a ground handover as to maintain the subnetwork connection with the ground DTE. Given that a new link would have to be established with the new ground station, it will be required to create a new 8208 Packet Level Entity over that link (creation of Subnet_Entity 2).

Once the aircraft LME has established a link with the new ground station that has access to the same ground DTE as the previous RGS, the LME will inform the VHF-SNDCF of the link change (LM_NOEXP_CALL.ind). The VHF-SNDCF in turn will initiate the subnetwork connection process (SC_NOEXP_CALL.ind) very similar to that of the subnetwork initiation process.

To support the above architecture the VHF-SNDCF (both on the ground and in the aircraft) will have to be able to associate a single local reference with successive logical channels. That is, the VHF-SNDCF must be able to map a remote SNPA with successive SVCs if the remote SNPA does not change. The mechanism that allows the aircraft entity to be explicitly notified that the "ATN contexts" have been maintain in the air/ground router, is via a Maintained/Initialize bit in the SNDCF parameter block sent between the peer entities via the CALL REQUEST/CONFIRM packet exchange. If the router does not have a subnetwork connection with that aircraft, or for any reason the router cannot maintain the "ATN contexts" for that aircraft, the router will respond with the Maintained/Initialized bit to 0 as part of the SNDCF parameter block. At this point, the IS-SME/9542 will have to re-initiate the IDRP and SNDCF Local Reference processes.

Therefore, if we assume that the A/G router can maintain the subnetwork connection with the aircraft, the only adjustment that is required is for the VHF-SNDCF to map the new SVC to the local reference of the previous SVC. There is no need to update the FIB or activate the IDRP process. It is assumed that once the new subnetwork connection has been successfully completed, the A/G router will send all traffic via the new path. However, given there may still be data being queued-up via the old link, the aircraft will maintain the previous link for a maximum time of TG5. During this time the aircraft will continue to accept and acknowledge frames on the previous link.

After TG5 time, both the previous link and the associated 8208 packet level entity will be terminated (DL_DISC.req, LM_DISC.ind).

DLS Test Scripts

Actions (A=):

A '|' implies a set of legal responses (that is, any one of the list is valid). A comma delimited list is a series of mandatory actions.

A1: If a ground IUT, discard frame. If an airborne IUT and sender is a ground station, send an XID_CMD_LE/P=1. If an airborne IUT and sender is an airborne station, discard frame.

A2: Disconnect the current connection and then perform A1.

A3: Perform other specified actions then, if an airborne IUT and sender is a ground station, send an XID_CMD_LE/P=1.

A5: Send a DM/F=0, then perform A3.

DI: Discard frame

frame type: send specified frame type

Parameters (P=):

State (S=):

ADM: asynchronous disconnected mode (force IUT into disconnected state before beginning test)

ABM: asynchronous balanced mode (force IUT into data transfer state before beginning test)

FRM: frame reject mode (force IUT to send FRMR from the ABM before beginning test)

SRM: sent selective reject Mode (force IUT to send SREJ from the ABM before beginning test)

Underlined stimuli are illegal frames which should never be transmitted; however, the IUT is being tested for its response against said frames. Underlined responses are alternate responses which I am not sure should be valid.

The response to any frame except for an XID (either transmitted or received) must be within T2 seconds. An XID response must be within T2 + 5 seconds.

Unless otherwise noted in a particular test case, the P0 set of parameter values will be used.

Parameter	Units	P0-set	P1-set	P2-set
MAC p		1	1	1

MAC M1		1	1	1
DLS T1min	sec	2	120	10
DLS T1max	sec	10	10	10
DLS T1mult		0	1	1
DLS T1exp		2	2	2
DLS T2	msec	500	500	500
DLS T4	min	15	1	15
DLS N1	bits	2168	2168	2168
DLS N2		3	3	3
DLS k	frames	4	4	4

The tests in this table do not test the ability to pass traffic (in the ABM and SRM), but the general responses to various frame types.

<table>
<tr><th>Row</th><th>Stimulus</th><th>Parm Set</th><th>ADM</th><th>ABM</th><th>SRM</th><th>FRM</th></tr>
<tr><td>B1</td><td>DISC/P = 1</td><td rowspan="23">P0</td><td rowspan="8">A = A1
S = ADM</td><td colspan="3" rowspan="8">A = A2
S = ADM</td></tr>
<tr><td>B2</td><td>DISC/P = 0</td></tr>
<tr><td>B3</td><td>DISC/F = 1</td></tr>
<tr><td>B4</td><td>DISC/F = 0</td></tr>
<tr><td>B5</td><td>DM/P = 1</td></tr>
<tr><td>B6</td><td>DM/P = 0</td></tr>
<tr><td>B7</td><td>DM/F = 1</td></tr>
<tr><td>B8</td><td>DM/F = 0</td></tr>
<tr><td>B9</td><td>RR/P = 1</td><td rowspan="2">A = A5
S = ADM</td><td>A = RR/F = 1
S = ABM</td><td>A = SREJ/F = 1
P = as last SREJ
S = SRM</td><td rowspan="4">A = FRMR/P = 1
P = as last FRMR
S = FRM</td></tr>
<tr><td>B12</td><td>RR/F = 0</td><td colspan="2">A = DI
S = same state</td></tr>
<tr><td>B13</td><td>UA/P = 1</td><td rowspan="2">A = DI | A5
S = ADM</td><td colspan="2" rowspan="10">A = FRMR/P = 1
P = W = 1/X = Y = Z = 0
S = FRM</td></tr>
<tr><td>B14</td><td>UA/P = 0</td></tr>
<tr><td>B15</td><td>UA/F = 1</td><td>A = A5
S = ADM</td><td>A = reset link
S = ABM</td></tr>
<tr><td>B16</td><td>UA/F = 0</td><td>A = DI | A5
S = ADM</td><td rowspan="7">A = FRMR/P = 1
P = per last FRMR
S = FRM</td></tr>
<tr><td>B18</td><td>DISC/P = 0, w/ info field</td><td rowspan="2">A = DI | A1
S = ADM</td></tr>
<tr><td>B24</td><td>DM/F = 0, w/ info field</td></tr>
<tr><td>B25</td><td>RR/P = 1, w/ info field</td><td rowspan="4">A = DI | A5
S = ADM</td></tr>
<tr><td>B27</td><td>RR/F = 1, w/ info field</td></tr>
<tr><td>B28</td><td>RR/F = 0, w/ info field</td></tr>
<tr><td>B31</td><td>UA/F = 1, w/ info field</td></tr>
<tr><td>B33</td><td>TEST/P = 1</td><td>A = TEST/F = 1, A3
P = copied from TEST command</td><td colspan="3">A = TEST/F = 1
P = copied from TEST command
S = same state</td></tr>
<tr><td>B34</td><td>TEST/P = 0</td><td>A = DI | A1</td><td colspan="3" rowspan="2">A = DI
S = same state</td></tr>
<tr><td>B35</td><td>TEST/F = 1</td><td>A = A1</td></tr>
</table>

<table>
<tr><td>B36</td><td>TEST/F=0</td><td>A=DI | A1</td><td colspan="2"></td></tr>
<tr><td>B37</td><td>RNR/P=1</td><td rowspan="3">A=DI | A5</td><td rowspan="14">A=FRMR/P=1
P=W=X=1/Y=Z=0
S=FRM</td><td rowspan="14">A=FRMR/P=1
P=as last FRMR
S=FRM</td></tr>
<tr><td>B38</td><td>SABM/P=1</td></tr>
<tr><td>B39</td><td>REJ/P=1</td></tr>
<tr><td>B40</td><td>RNR/P=0</td><td rowspan="11">A=DI | A5</td></tr>
<tr><td>B41</td><td>RNR/F=1</td></tr>
<tr><td>B42</td><td>RNR/F=0</td></tr>
<tr><td>B47</td><td>REJ/P=0</td></tr>
<tr><td>B48</td><td>REJ/F=1</td></tr>
<tr><td>B49</td><td>REJ/F=0</td></tr>
<tr><td>B54</td><td>SABM/P=0</td></tr>
<tr><td>B55</td><td>SABM/F=1</td></tr>
<tr><td>B56</td><td>SABM/F=0</td></tr>
<tr><td>B61</td><td>broadcast UI/P=0</td><td>A=process, A3
S=ADM</td><td colspan="2">A=process
S=same state</td></tr>
<tr><td>B62</td><td>multicast UI/P=0 to all aircraft</td><td rowspan="4">A=process if IUT type is same as destination address, A3
S=ADM</td><td colspan="2" rowspan="4">A=process if IUT type is same as destination address
S=same state</td></tr>
<tr><td>B63</td><td>multicast UI/P=0 to all ground stations</td></tr>
<tr><td>B64</td><td>multicast UI/P=0 to all ground stations of a different provider</td></tr>
<tr><td>B65</td><td>multicast UI/P=0 to all ground stations of this provider</td></tr>
<tr><td>B66</td><td>broadcast UI/P=1</td><td rowspan="2">A=A1
S=ADM</td><td colspan="2" rowspan="2">A=DI
S=same state</td></tr>
<tr><td>B67</td><td>unicast UI/P=0</td></tr>
<tr><td>B68</td><td>FRMR/P=1 from a lower-numbered station</td><td rowspan="3">A=A5
S=ADM</td><td colspan="2">A=UA/F=1, clear state
S=ABM</td></tr>
<tr><td>B69</td><td>FRMR/F=1 from a lower-numbered station</td><td colspan="2" rowspan="2">A=DI | UA/F=1
S=ABM</td></tr>
<tr><td>B70</td><td>FRMR/P=0 from a lower-numbered station</td></tr>
</table>

<table>
<tr><td>B71</td><td>FRMR/F = 0 from a lower-numbered station</td><td rowspan="7"></td><td></td><td colspan="3"></td></tr>
<tr><td>B72</td><td>INFO/P = 0 with bad FCS</td><td colspan="4" rowspan="2">A = DI
S = same state</td></tr>
<tr><td>B73</td><td>INFO/P = 0 that is aborted</td></tr>
<tr><td>B74</td><td>INFO/P = 0 with valid FCS but non-integral number of octets</td><td colspan="4">A = DI
S = same state</td></tr>
<tr><td>B82</td><td>SREJ/P = 1</td><td>S = A5
S = ADM</td><td>A = RR/F = 1 |
INFO/F = 1
S = ABM</td><td>A = SREJ/F = 1
S = SRM</td><td>A = FRMR/F = 1
P = as last FRMR
S = FRM</td></tr>
<tr><td>B83</td><td>SREJ/P = 0</td><td rowspan="2">A = DI | A5
S = ADM</td><td colspan="2" rowspan="2">A = FRMR/P = 1
P = W = 1/X = Y = Z = 0
S = FRM</td><td rowspan="2">A = FRMR/P = 1
P = as last FRMR
S = FRM</td></tr>
<tr><td>B85</td><td>SREJ/F = 0</td></tr>
<tr><td>B86</td><td>no stimulus for T4</td><td rowspan="4">P1</td><td rowspan="4">A = DI</td><td rowspan="3">A = RR/P = 1 |
INFO/P = 1
S = ABM (**verify that the exponential backoff works)</td><td rowspan="3">A = SREJ/P = 1
S = SRM (**verify that the exponential backoff works)</td><td rowspan="3">A = FRMR/P = 1
S = FRM (**verify that the exponential backoff works)</td></tr>
<tr><td>B87</td><td>B86: no stimulus for T1</td></tr>
<tr><td>B88</td><td>B87: no stimulus for T1</td></tr>
<tr><td>B89</td><td>B88: no stimulus for T1</td><td colspan="3">A = inform LME
S = same state</td></tr>
<tr><td>B90</td><td>TEST/P = 1 with right destination address, but no source address</td><td rowspan="8">P0</td><td colspan="4" rowspan="2">A = DI
S = same state</td></tr>
<tr><td>B91</td><td>broadcast UI/P = 0 with no source address</td></tr>
<tr><td>B92</td><td>broadcast UI/P = 0 from an unknown type</td><td colspan="4">A = DI | process
S = same state</td></tr>
<tr><td>B94</td><td>INFO/P = 0 with unknown source address</td><td>A = A5</td><td colspan="3">A = DM/F = 0 (to second tester address)
S = same state (first tester address), ADM (second tester address)</td></tr>
<tr><td>B95</td><td>INFO/P = 0 with modulo 128 format</td><td>A = DI | A5</td><td colspan="3">S = FRMR/P = 1
P = W = 1/X = Y = X = 0
S = FRM</td></tr>
<tr><td>B96</td><td>INFO/P = 0 with missing leading flag</td><td colspan="4" rowspan="2">A = DI
S = same state</td></tr>
<tr><td>B97</td><td>broadcast UI/P = 0 with source address as broadcast address</td></tr>
<tr><td>B98</td><td>unicast UI/P = 1</td><td>A = DI
S = ADM</td><td colspan="2">A = FRMR/P = 1
P = W = X = 1/Y = Z = 0
S = FRM</td><td>A = FRMR/P = 1
P = as last FRMR
S = FRM</td></tr>
</table>

B99	FRMR/P = 1 from a higher numbered station		A = A5 S = ADM	A = UA/F = 1, clear state S = ABM	A = DI S = FRM
B100	FRMR/P = 0 from a higher numbered station			A = DI | UA/F = 1, clear state S = ABM	
B101	FRMR/F = 1 from a higher numbered station				
B102	FRMR/F = 0 from a higher numbered station				

The tests in this table are intended to verify that the IUT can successfully pass traffic in both directions. All tests are to be performed with the IUT in the ABM state. Those rows marked with a '*' are also to be performed with the IUT starting in the SRM state (this is achieved by first sending the IUT an INFO/P=0 (N(s)=1, N(r)=0)).

With all tests, the V(s) and V(r) of the IUT shall be 0 (except as described in the next sentence). If the stimulus is a semi-colon-separated pair, the second stimulus should be presented after the IUT successfully passes the named first test. A comma-separated list of stimuli should be transmitted to the IUT in a single transmission, with a single flag between frames.

A "DATA" stimulus is a data packet causing the IUT to transmit an INFO frame with the indicated parameters.

Abbreviations:

S = N(s)
R = N(r)
1 (in SREJ) = a byte in the information field acknowledges sequence number 1
/2 (in SREJ) = a byte in the information field naks sequence number 2

Row	Stimulus	Parm Set	Response	Comments
C1	INFO/P=0 (S=0, R=0)	P0	A=RR/F=0 (R=1) S=ABM	Receiving every sequence number
C2	INFO/P=0 (S=1, R=0)		A=SREJ/F=0 (R=0, 1) S=SRM	
C3	INFO/P=0 (S=2, R=0)		A=SREJ/F=0 (R=0, /1, 2) S=SRM	
C4	INFO/P=0 (S=3, R=0)		A=SREJ/F=0 (R=0, /1, /2, 3) S=SRM	
C5	INFO/P=0 (S=4, R=0)		A=RR/F=0 (R=0) S=ABM	
C6	INFO/P=0 (S=5, R=0)		A=RR/F=0 (R=0) S=ABM	
C7	INFO/P=0 (S=6, R=0)		A=RR/F=0 (R=0) S=ABM	
C8	INFO/P=0 (S=7, R=0)		A=RR/F=0 (R=0) S=ABM	
C9*	INFO/P=0 (S=0, R=1)		A=FRMR/P=1 P=Z=1/W=X=Y=1 S=FRM	illegal frame check
C10	C1: INFO/P=0 (S=1, R=0)		A=RR/F=0 (R=2) S=ABM	rotate the receive window
C11	C10: INFO/P=0 (S=2, R=0)		A=RR/F=0 (R=3) S=ABM	

C12	C11: INFO/P = 0 (S = 3, R = 0)		A = RR/F = 0 (R = 4) S = ABM	
C13	C12: INFO/P = 0 (S = 4, R = 0)		A = RR/F = 0 (R = 5) S = ABM	
C14	C13: INFO/P = 0 (S = 5, R = 0)		A = RR/F = 0 (R = 6) S = ABM	
C15	C14: INFO/P = 0 (S = 6, R = 0)		A = RR/F = 0 (R = 7) S = ABM	
C16	C15: INFO/P = 0 (S = 7, R = 0)		A = RR/F = 0 (R = 0) S = ABM	
C17	INFO/P = 0 (S = 0, R = 0), INFO/P = 0 (S = 1, R = 0)		A = RR/F = 0 (R = 2) S = ABM	Verify that can receive various numbers of frames with a single flag delimiter
C18	INFO/P = 0 (S = 0, R = 0), INFO/P = 0 (S = 1, R = 0), INFO/P = 0 (S = 2, R = 0)		A = RR/F = 0 (R = 3) S = ABM	
C19	INFO/P = 0 (S = 0, R = 0), INFO/P = 0 (S = 1, R = 0), INFO/P = 0 (S = 2, R = 0), INFO/P = 0 (S = 3, R = 0)		A = RR/F = 0 (R = 4) S = ABM	
C21	C2:INFO/P = 0 (S = 0, R = 0)		A = RR/F = 0 (R = 2) (two frames delivered in order) S = ABM	deliver out-of-order traffic correctly
C22*	DATA		A = INFO/P = 0 (S = 0, R = 0) S = same state	can transmit traffic
C23*	C22: no stimulus for T1		A = INFO/P = 0 (S = 0, R = 0) S = same state	retransmit OK
C24*	C23: no stimulus for T1		A = INFO/P = 0 (S = 0, R = 0) S = same state	
C25*	C24: no stimulus for T1		A = inform LME S = same state	
C26*	DATA, DATA	P2	A = INFO/P = 0 (S = 0, R = 0), INFO/P = 0 (S = 1, R = 0) S = same state	
C27*	C26: SREJ/F = 0 (R = 0, 1)		A = INFO/P = 0 (S = 0, R = 0) S = same state	only retransmit nak'ed traffic
C28*	C27: DATA (after T1/2 seconds)		A = INFO/P = 0 (S = 2, R = 0) S = same state	
C29*	C28: no stimulus for T1 (since C26)		A = INFO/P = 0 (S = 0, R = 0) S = same state	only transmit traffic sufficiently old
C30*	C29: no stimulus for T1		A = inform LME S = same state	properly count N1
C31*	DATA, DATA, DATA, DATA	P0	A = INFO/P = 0 (S = 0, R = 0), INFO/P = 0 (S = 1, R = 0), INFO/P = 0 (S = 2, R = 0), INFO/P = 0 (S = 3, R = 0) S = same state	can transmit 4 frames properly

C32*	C31: SREJ/F=0 (R=0, /1, /2, 3)	A=INFO/P=0 (S=0, R=0), INFO/P=0 (S=1, R=0), INFO/P=0 (S=2, R=0) S=same state	only transmit nak'ed frames
C33*	C32: SREJ/F=0 (R=1, /2, 3)	A=INFO/P=0 (S=1, R=0), INFO/P=0 (S=2, R=0) S=same state	
C34*	C33: DATA, DATA	A=INFO/P=0 (S=4, R=0) S=same state	respect send window
C35*	C34: RR/F=0 (R=5)	A=INFO/P=0 (S=5, R=0) S=same state	
C36	INFO/P=0 (S=3, R=0)	A=SREJ/F=0 (R=0, /1, /2, 3) S=SRM	send appropriate SREJ
C37	C36: INFO/P=0 (S=0, R=0)	A=SREJ/F=0 (R=1, /2, 3), (one frame delivered) S=SRM	
C38	C37: INFO/P=0 (S=4, R=0)	A=SREJ/F=0 (R=1, /2, 3, 4) S=SRM	
C39:	C38: INFO/P=0 (S=5, R=0)	A=SREJ/F=0 (R=1, /2, 3, 4) (** link renegotiation should occur to reset k **) S=SRM	
C40	INFO/P=0 (S=0, R=0), INFO/P=0 (S=2, R=0)	A=SREJ/F=0 (R=1, 2) S=SRM	
C41*	C26: no stimulus for T1	A=INFO/P=0 (S=0, R=0), INFO/P=0 (S=1, R=0) S=same state	retransmit all outstanding frames
C42*	C26: SREJ/F=0 (R=0, 1), TEST/P=1	A=TEST/F=1, INFO/P=0 (S=0, R=0) S=same state	transmit supervisory frames before INFO frames
C43*	C26: SREJ/F=0 (R=0, 1), SREJ/F=0 (R=0, 1)	A=INFO/P=0 (S=0, R=0) S=same state	only queue one INFO regardless of number of SREJ
C44*	C22: DATA, RR/F=0 (R=1)	A=INFO/P=0 (S=1, R=0) S=same state	can transmit properly
C45*	C44: DATA, RR/F=0 (R=2)	A=INFO/P=0 (S=2, R=0) S=same state	
C46*	C45: DATA, RR/F=0 (R=3)	A=INFO/P=0 (S=3, R=0) S=same state	
C47*	C46: DATA, RR/F=0 (R=4)	A=INFO/P=0 (S=4, R=0) S=same state	
C48*	C47: DATA, RR/F=0 (R=5)	A=INFO/P=0 (S=5, R=0) S=same state	
C49*	C48: DATA, RR/F=0 (R=6)	A=INFO/P=0 (S=6, R=0) S=same state	
C50*	C49: DATA, RR/F=0 (R=7)	A=INFO/P=0 (S=7, R=0) S=same state	
C51*	C50: DATA, RR/F=0 (R=0)	A=INFO/P=0 (S=0, R=0) S=same state	

C52	INFO/P = 1 (S = 0, R = 0)	A = RR/F = 1 (R = 1) S = ABM	sets F bit properly
C53*	INFO/P = 0 (S = 0, R = 1), INFO/P = 0 (S = 1, R = 1)	A = FRMR/P = 1 P = Z = 1/W = X = Y = 1 S = FRM	sends only one FRMR per transmission
C54	INFO/P = 0 (S = 0, R = 0) with no info field	A = RR/F = 0 (R = 1) S = ABM	accepts minimum sized INFO frame
C55	INFO/P = 0 (S = 0, R = 0) with info field containing 8208 DATA packet of 256 octets	A = RR/F = 0 (R = 1) S = ABM	accepts maximum sized INFO frame
C56	INFO/P = 0 (S = 0, R = 0) with info field containing 8208 DATA packet of 257 octets	A = FRMR/P = 1 P = Y = 1/W = X = Z = 0 S = FRM	reject too large INFO frame
C57*	C31: SREJ/F = 0 (R = 0, /0, /1, /2, 3)		rejects illegal SREJ
C58*	C31: SREJ/F = 0 (R = 0, 5)	A = FRMR/P = 1 P = Z = 1/W = X = Y = 0 S = FRM	
C59*	C31: SREJ/F = 0 (R = 6)		
C60*	C31: SREJ/F = 0 (R = 0, 3, /4)		
C61*	C22: RR/F = 1 (R = 1) (unsolicited F = 1)	A = DI (note N(r) *not processed*)	discards illegal RR

Additional tests not specified in tabular form:

D1 - Verify that a ground IUT always has the A/G bit set to 1.

D2 - Verify that an aircraft IUT which cannot switch the A/G bit has it set to 1.

D3 - Verify that an aircraft IUT which can switch the A/G bit sets it appropriately.

D4 - Verify that an IUT, after having transmitted a FRMR, retransmits it according to the T1 procedures up to N2 times and then informs the LME.

LME Test Scripts

AIRCRAFT LME

EXPLANATIONS:

S = state
A = action
GS-c = current Ground Station (either the only GS with which a link is established or the active link when in the process of handoff)
GS-n = new Ground Station (just after a successful handoff this is the 'freshly' established link)
GS-p = proposed Ground Station (during handoff this is the new GS with which the aircraft proposes to establish a link)
GS-o = old Ground Station, in a link overlap situation, this is the GS which was the current GS until the new link was established and for which the overlap timer TG5 has been started
GS-x = other Ground Station, that is a GS which is not one of active stations as explained in 'GS:x,y'.
GS-active = one of the active stations as explained in 'GS:x,y'.
DI = Discard the received input
ADM = Asynchronous Disconnect Mode
LE_pend. = Link establishment pending
ABM_Single = Link established with a single GS
ABM_Mult. = Link established with two GSss at the same time. One link is with the current GS, the other is with the new GS. The link with GS-c will only be maintained for TG5 time interval.
HO_pend. = Handoff pending state. In this state the link with the current GS is maintained while the link with the proposed GS is in the process of being set up but is not established yet.
*n = reference number of an explanatory footnote
GS:x,y list of GSs with which the a/c is communicating (and expecting semantically correct responses) in a particular state.

GENERAL COMMENTS:

1. This table represent the behaviour of the aircraft LME and only air intiated handoffs are considered.

2. All XID frames transmitted by a/c have C/R bit = 0 (command).

3. Handoffs are done between ground stations of the same operator.