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Manual on VHF Digital Link (VDL) Mode 2

Approved by the Secretary General
and published under his authority

Second Edition — 2015

International Civil Aviation Organization

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Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

First edition 2001
Second edition 2015

Doc 9776, Manual on VHF Digital Link (VDL) Mode 2
Order Number: 9776
ISBN 978-92-9249-681-4

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AMENDMENTS

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FOREWORD

Standards and Recommended Practices (SARPs) for very high frequency (VHF) digital link (VDL) Modes 1 and 2 were developed by the Aeronautical Mobile Communications Panel (AMCP) and introduced in Annex 10, *Aeronautical Telecommunications*, Volumes III and V in 1997 as a part of Amendment 72 to the Annex. References to VDL Mode 1 were removed from the Annex as part of Amendment 76 to Annex 10. The VDL system provides air-ground subnetwork services within the aeronautical telecommunication network (ATN).

During the development of the VDL SARPs and validation activities, the AMCP produced the material contained in this manual.

The purpose of the manual is to provide guidance when implementing VDL Mode 2. This manual is to be used in conjunction with the relevant provisions in Annex 10, Volumes III and V.

Comments on this document would be appreciated from all parties involved in the implementation of aeronautical mobile communication. These comments should be addressed to:

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TABLE OF CONTENTS

	<i>Page</i>
Acronyms and abbreviations	(xi)
 PART I. IMPLEMENTATION ASPECTS	
Chapter 1. Definitions and system capabilities	I-1-1
1.1 Background	I-1-1
1.2 Compatibility	I-1-1
1.3 General architecture	I-1-1
1.4 Ground infrastructure options	I-1-2
1.5 Interoperability	I-1-3
1.6 Subnetwork selection	I-1-3
1.7 Frequency management	I-1-3
1.8 Common signalling channel	I-1-3
1.9 Naming convention	I-1-4
1.10 Sub-layer relationship	I-1-4
1.11 External interfaces	I-1-5
 Chapter 2. Physical layer protocols and services	 I-2-1
2.1 Introduction	I-2-1
2.2 Functions	I-2-1
2.3 Physical layer system parameters	I-2-4
2.4 Interface to upper layers	I-2-4
2.5 Interface to physical processes	I-2-7
2.6 SDL description	I-2-8
2.7 States	I-2-8
 Chapter 3. Link layer protocols and services	 I-3-1
3.1 General information	I-3-1
3.2 Media access control (MAC) sub-layer	I-3-1
3.3 Data link sub-layer	I-3-3
3.4 Link management entity (LME)	I-3-15
3.5 LME test scripts	I-3-20
 Chapter 4. Subnetwork layer protocols and services	 I-4-1
4.1 Architecture	I-4-1
4.2 Functions	I-4-1
4.3 Interface to peer entities	I-4-1
4.4 Interface to upper layer	I-4-2

	Page
Chapter 5. VDL Mode 2 subnetwork connection management	I-5-1
5.1 Introduction.....	I-5-1
5.2 VDL Mode 2 subnetwork connection management overview	I-5-2
5.3 VDL Mode 2 system management entities	I-5-3
5.4 VDL Mode 2 subnetwork initiation process.....	I-5-4
Appendix to Part I.	
DLS test scripts	I-App-1
LME test scripts.....	I-App-11
VDL MODE 2 MSCs.....	I-App-27

PART II. DETAILED TECHNICAL SPECIFICATIONS

1. Definitions and system capabilities	II-1
1.1 Definitions.....	II-1
1.2 Radio channels and functional channels	II-4
1.3 System capabilities.....	II-5
1.4 Air-ground VHF digital link communications systems characteristics	II-5
2. System characteristics of the ground Installation.....	II-5
3. System characteristics of the aircraft installation.....	II-5
4. Physical layer protocols and services.....	II-6
4.1 Functions.....	II-6
4.2 Mode 2 physical layer.....	II-6
5. Link layer protocols and services.....	II-6
5.1 General information	II-6
5.2 Mode 2 MAC sub-layer.....	II-6
5.3 Mode 2 data link service sub-layer	II-8
5.4 Mode 2 VDL management entity.....	II-15
6. Subnetwork layer protocols and services.....	II-30
6.1 Architecture	II-30
6.2 Services.....	II-30
6.3 Packet format	II-32
6.4 Subnetwork layer service system parameters	II-33
6.5 Effects of layers 1 and 2 on the subnetwork layer	II-34
6.6 Description of procedures.....	II-34

	Page
7. The VDL mobile subnetwork dependent convergence function (SND CF)	II-36
7.1 Introduction.....	II-36
7.2 Call user data encoding.....	II-36
8. Tables for the <i>Manual on VHF Digital link (VDL) Mode 2</i> technical specifications	II-37
9. References	II-62
9.1 Normative references	II-62
9.2 Background references	II-62

ACRONYMS AND ABBREVIATIONS

ABM	asynchronous balanced mode
ACK	acknowledge(ment)
ADM	asynchronous disconnected mode
A/G	air-ground
AIHO	Aircraft-initiated handoff
AMCP	Aeronautical Mobile Communications Panel
AMS(R)S	aeronautical mobile-satellite (route) service
AOC	aeronautical operational communication
AOA	ACARS over AVLK
ARS	administrative region selection
ATC	air traffic control
ATN	aeronautical telecommunication network
ATS	air traffic services
ATSC	ATS communications
AVLC	aviation VHF link control
BCD	binary coded decimal
BER	bit error rate
BIS	boundary intermediate system
CAA	civil aviation administration
CCIR	International Radio Consultative Committee
CLAMN	called line address modification notification
CLNP	connectionless network protocol
CMD	command (frame)
CNS	communication, navigation and surveillance
COTS	connection-oriented transport service
CPU	central processing unit
C/R	command/response (bit)
CSC	common signalling channel
CSMA	carrier sense multiple access
CU	control unit
CW	continuous wave
D8PSK	differentially encoded 8 phase shift keying
DCE	data circuit-terminating equipment
DISC	disconnect (frame)
DLE	data link entity
DLPDU	data link protocol data unit
DLS	data link service
DM	disconnected mode (frame)
DOC	designated operational coverage
DSB-AM	double sideband-amplitude modulation
DTE	data terminal equipment
DXE	denotes either: data terminal equipment, or data circuit-terminating equipment
ES-IS	end systems-intermediate systems
FCS	frame check sequence
FEC	forward error correction
FIB	forwarding information base

FRM	frame reject mode
FRMR	frame reject (frame)
FSL	frequency support list
GI	group identification (field)
GRAIHO	ground-requested aircraft-initiated handoff
GS	ground station
GSIF	ground station information frame
HDL	high-level data link control
HIC	highest incoming channel
HO	handoff
HOC	highest outgoing channel
HTC	highest two-way channel
ID	identification (identifier)
IDRP	inter-domain routing protocol
INFO	information (frame)
ISH	intermediate system hello (packet)
ISO	International Organization for Standardization
IS-SME	intermediate system – system management entity
ITU-R	International Telecommunication Union — Radio Communication Sector
IUT	internal uniform timer
LCR	link connection refused
LIC	lowest incoming channel
LLC	logical link control
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
NET	network entity title
OSI	open systems interconnection
PDU	protocol data unit
PEC	peer entity contact table
P/F	poll/final (bit)
PN	pseudo noise
Q-bit	qualifier bit
QOS	quality-of-service
REJ	reject (frame)
RF	radio frequency
RGS	remote ground station
RNR	receive not ready (frame)
RP	routing information exchange protocol
RR	receive ready (frame)
RSP	response (frame)
RVC	redirected virtual circuit
SABM	set asynchronous balanced mode
SARPs	Standards and Recommended Practices
SDL	specification and description language
SDU	service data unit
SME	system management entity

SNAcP	subnetwork access protocol
SNDCF	subnetwork dependent convergence function
SNPA	subnetwork point of attachment
SNPDU	subnetwork protocol data unit
SNR	signal to noise ratio
SNSAP	subnetwork service access point
SN-SME	subnetwork – system management entity
SQP	signal quality parameter
SP	service provider
SREJ	multi-selective reject
SRM	sent selective reject mode
SVC	switched virtual circuit
TDMA	time division multiple access
TCP/IP	transport control protocol /internetworking protocol
UA	unnumbered acknowledgement (frame)
UI	unnumbered information (frame)
VDL	VHF digital link
VDLM2	VHF digital link Mode 2
VDR	VHF data radio
VHF	very high frequency
VME	VHF management entity
VSDA	VDL specific DTE addressing
XID	exchange ID (frame)
XOR	exclusive OR

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PART I

Implementation aspects

Chapter 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 for 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 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 conformant 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). Figure I-1-1 presents the VDL system within the ATN protocol architecture.

1.3 GENERAL ARCHITECTURE

1.3.1 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.

1.3.2 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 lower sub-layer of the network layers. The modulation scheme that has been defined for the VDL physical layer can interoperate with the upper layers without affecting the protocol stack.

1.3.3 The aviation VHF link control (AVLC) layer conforms to the high-level data link control (HDLC) as specified by ISO 3309, ISO 4335, ISO 7809 and ISO 8885. However, given that HDLC was designed 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 air-ground (A/G) subnetwork conforms to ISO 8208.

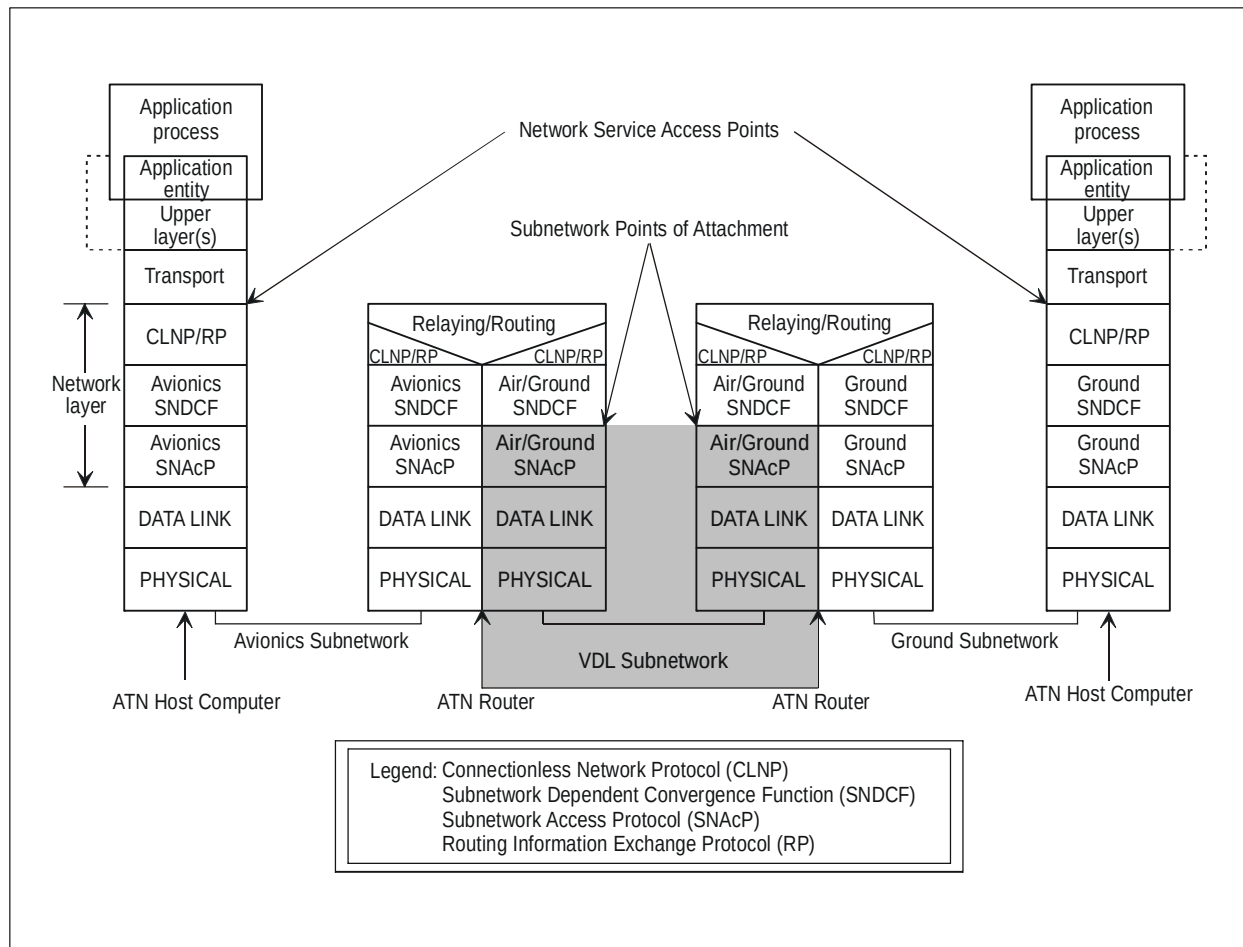


Figure I-1-1. ATN protocol architecture

1.4 GROUND INFRASTRUCTURE OPTIONS

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

- VDL and ATN network operated by the Civil Aviation Administration (CAA)* — only CAA-operated VDL ground stations, connected to CAA router(s), providing at least ATS communications (ATSC);
- VDL and ATN network operated by a commercial services provider* — only ground stations operated by a commercial services provider, supporting aeronautical operational communication (AOC) and, if so required by the local CAA, ATSC, and connected to the service provider router, which may be located in a different State;
- VDL network and ATN network operated by both a commercial services provider and the CAA* — ground stations providing both AOC and ATSC, simultaneously connected to an AOC router (which may be outside the State) and to a CAA router (within the State); and

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

1.5 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), Mode S data link, HF data link, VDL Mode 3 and VDL Mode 4.

1.6 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.

1.7 FREQUENCY MANAGEMENT

Frequency management is a cooperative 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.

1.8 COMMON SIGNALLING CHANNEL

The designation of a common signalling 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 returned 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.

1.9 NAMING CONVENTION

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

<i>Protocol sub-layer</i>	<i>Single-letter identifier</i>	<i>Two-letter identifier</i>
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

1.10 SUB-LAYER RELATIONSHIP

Figure I-1-2 shows the relationship between the sub-layers, including the primitives which flow between the sub-layers. The primitives outlined in Figure I-1-2 are also outlined in the Appendix to Part 1 of this manual 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 (HO);
- c) VHF subnetwork expedited subnetwork HO; and
- d) VHF subnetwork termination process.

1.11 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 transmitting entity:

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

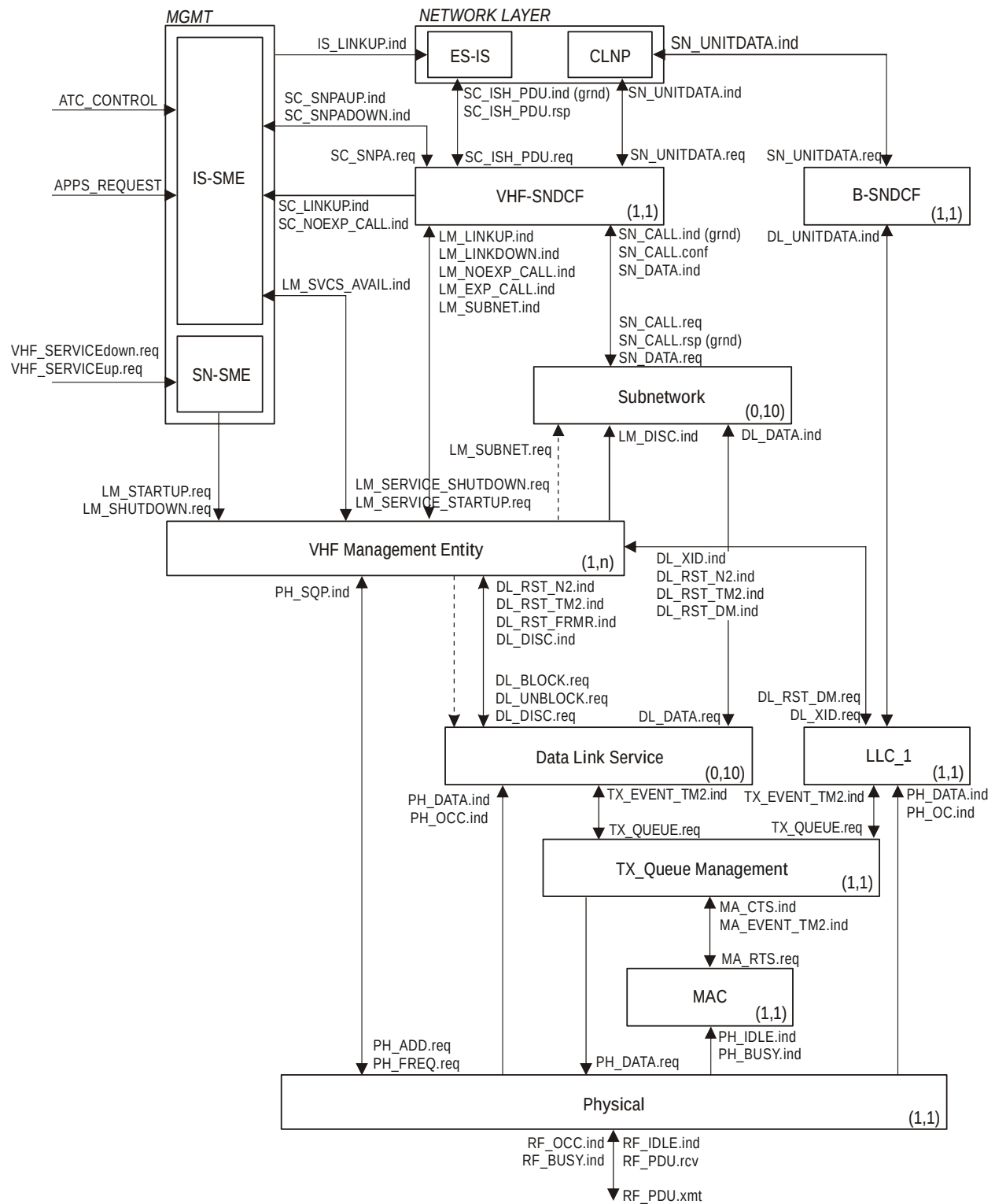


Figure I-1-2. Primitive flow diagram

Chapter 2

PHYSICAL LAYER PROTOCOLS AND SERVICES

2.1 INTRODUCTION

2.1.1 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 the physical layer:

- 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.

2.1.2 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 medium 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.

2.2.3 Transmission characteristics for VDL Mode 2

2.2.3.1 VDL Mode 2 modulation. Differentially encoded 8 phase shift keying (D8PSK) may be produced by combining two quadrature radio frequency (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.

2.2.3.1.1 Multi-phase encoding. The VDL Mode 2 modulation scheme will use the Gray Coding method to map or assign the 3-bit information bits into one of the eight possible phases. Gray Coding is one in which adjacent phases differ by one binary digit as illustrated in Figure I-2-1. The most likely errors caused by noise involve the erroneous selection of an adjacent phase to the transmitted signal phase; by using the Gray Coding method only a single bit error occurs in the 3-bit sequence.

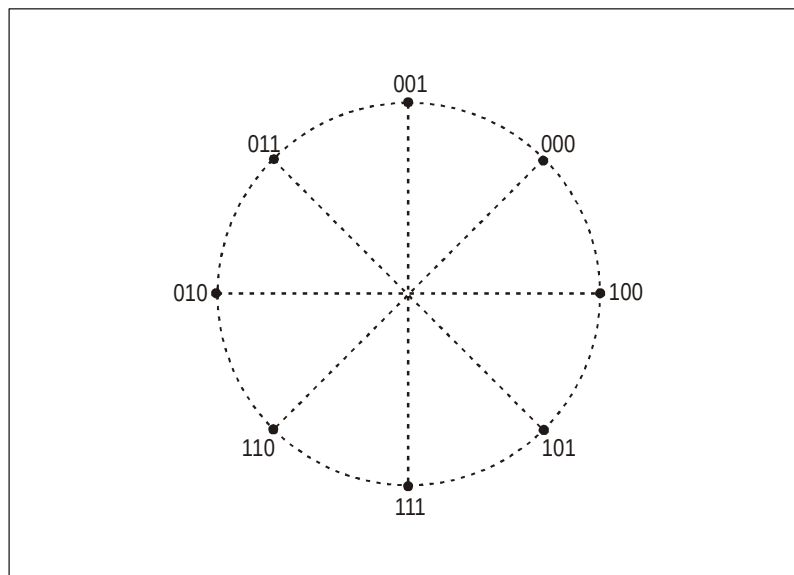


Figure I-2-1. Phase diagram of D8PSK with gray coding

2.2.3.1.2 VDL Mode 2 rate. Future modes of VDL that incorporate time division multiple access (TDMA) schemes may employ the baseband symbol clock to maintain timing for media access. In this case, it is expected that ground equipment supporting TDMA schemes will require a tolerance in the baseband symbol clock of at least ± 0.001 per cent.

2.2.3.2 Forward error correction (FEC). 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 I-2-1.

Table I-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

2.2.3.3 **Functional block diagram.** Figure I-2-2 shows a functional block diagram for VDL Mode 2 message encoding.

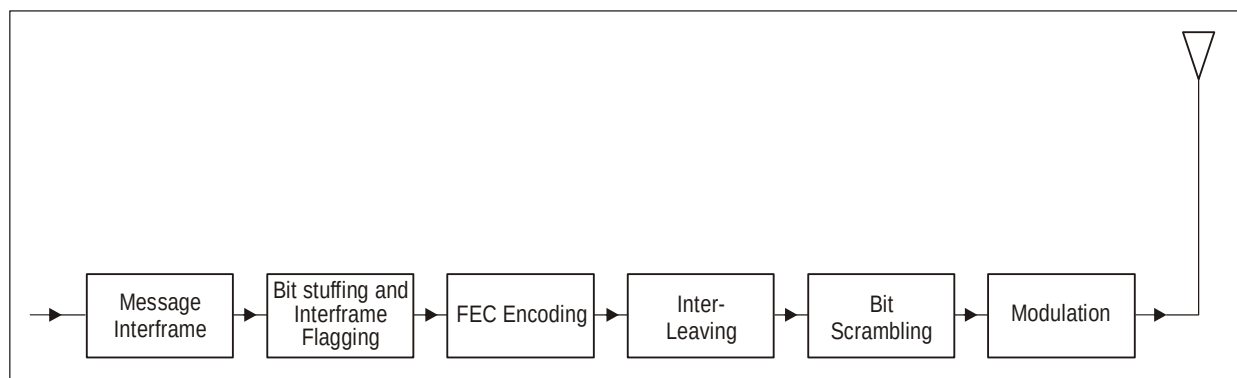


Figure I-2-2. Message encoding block diagram

2.2.3.4 Training sequence for VDL Mode 2

2.2.3.4.1 **Unique word.** In an environment with an E_b/N_0 of 13 dB (a bit error rate (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} .

2.2.3.4.2 **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.

2.2.4 Channel sense algorithms

2.2.4.1 When running a carrier sense multiple access (CSMA) algorithm prior to transmitting data or packetized voice, the VDL Mode 2 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.

2.2.4.2 Channel quiescent value. Whenever the VDL Mode 2 is not transmitting or receiving a message, the VDL calculates a channel quiescent value, T_b , according to the following algorithm:

$$T_q[n+1] = \begin{cases} T_q[n] + k(L, T_q[n]) (L - T_q[n]), & L \leq T_{\max} \\ T_{\max}, & \text{otherwise} \end{cases}$$

where

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

and

$$k(L, T_q) = \max(0.01^{(L/T_q)}, 1/16384)$$

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

2.2.4.3 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.

2.2.4.4 Synchronization. If synchronization is not achieved (i.e. the unique word is not detected) within 2.5 milliseconds, 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.

2.2.4.5 Receiver/transmitter interactions. The receiver/transmitter interactions are given in Figure I-2-3.

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

2.3. PHYSICAL LAYER SYSTEM PARAMETERS

The minimum transmission length that a receiver is capable of demodulating without degradation of BER for VDL Mode 2 is 131 071 bits. However, this is the maximum length expected to be transmitted.

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

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

2.4 INTERFACE TO UPPER LAYERS

Note.— Primitives associated with the VDL Mode 2 are as detailed in 2.4.1 through 2.4.6.

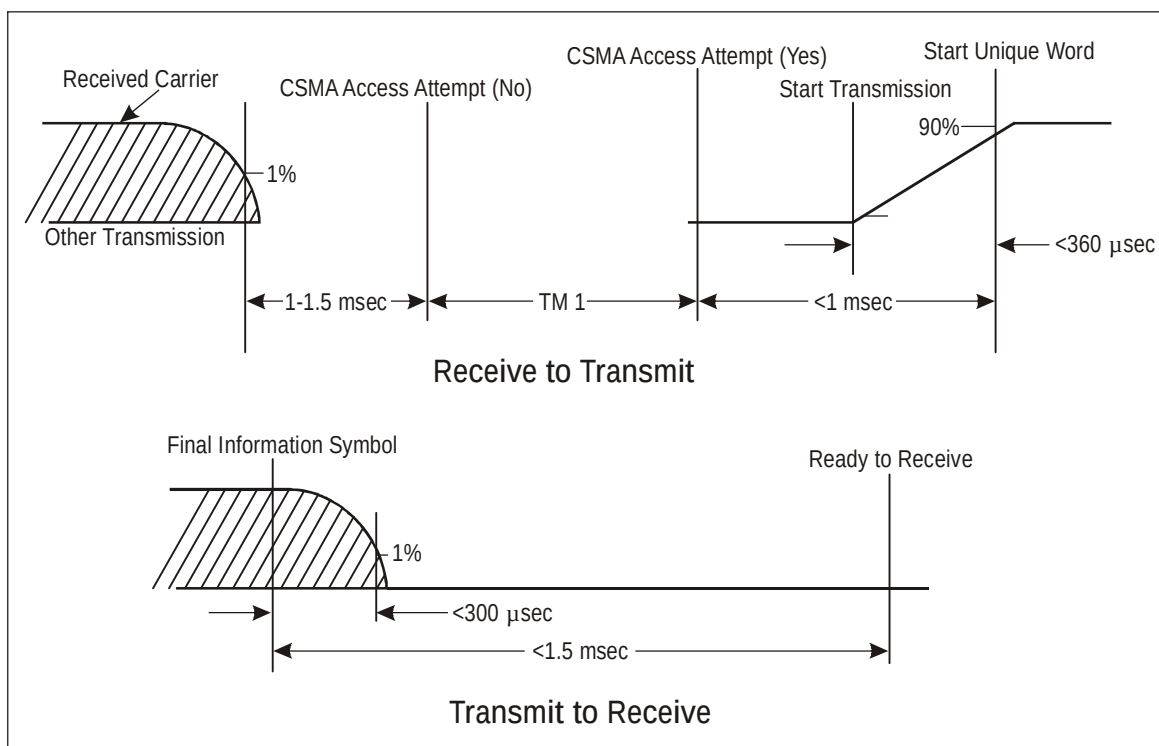


Figure I-2-3. Turnaround time requirements

2.4.1 Data

The PH_DATA primitives are passed between the data link service (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

2.4.1.1 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 (mandatory (M)) (contains physical layer service data unit [SDU]).

2.4.1.2 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).

2.4.2 Change frequency and mode

PH_FREQ.request is the service request primitive for the frequency request service. This primitive is generated by the link management entity (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)

2.4.3 Channel sense

2.4.3.1 The following primitives are passed from the physical layer to the media access control (MAC) sub-layer to support the CSMA algorithm:

PH_BUSY.indication
PH_IDLE.indication

2.4.3.2 **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.

2.4.3.3 **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.

2.4.4 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)

2.4.5 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 established 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.

2.4.6 Channel occupancy

2.4.6.1 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 used to compute the retransmission interval. This primitive is generated periodically with a value between 0 and 1.

2.4.6.2 The following is an example of one control unit (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 per cent 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)

2.5. INTERFACE TO PHYSICAL PROCESSES

Note.— Primitives associated with the VDL Mode 2 are as detailed in 2.5.1 and 2.5.2.

2.5.1 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

2.5.1.1 **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)

2.5.1.2 **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)

2.5.2 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

2.5.2.1 **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.

2.5.2.2 **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.

2.5.2.3 **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 a measurement of the channel occupancy.

2.6 SDL DESCRIPTION

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

2.7 STATES

The physical layer is stateless.

Chapter 3

LINK LAYER PROTOCOLS AND SERVICES

3.1 GENERAL INFORMATION

3.1.1 The link layer is responsible for transferring information from one network entity to another, for announcing errors encountered during transmission and for providing the following services:

- a) assembly and disassembly of frames;
- b) establishment of frame synchronization;
- c) rejection of non-standard 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.

3.1.2 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 $M1 = \lceil \log(1 - v) / \log(1 - p) \rceil$. 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 interval 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 I-3-1 summarizes the timers used in the MAC sub-layer.

Table I-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

3.2.1.4.1 Figure I-3-1 provides an overview of the VDL Mode 2 MAC timers as well as the MAC processes which are executed when a station is attempting to access the VHF channel.

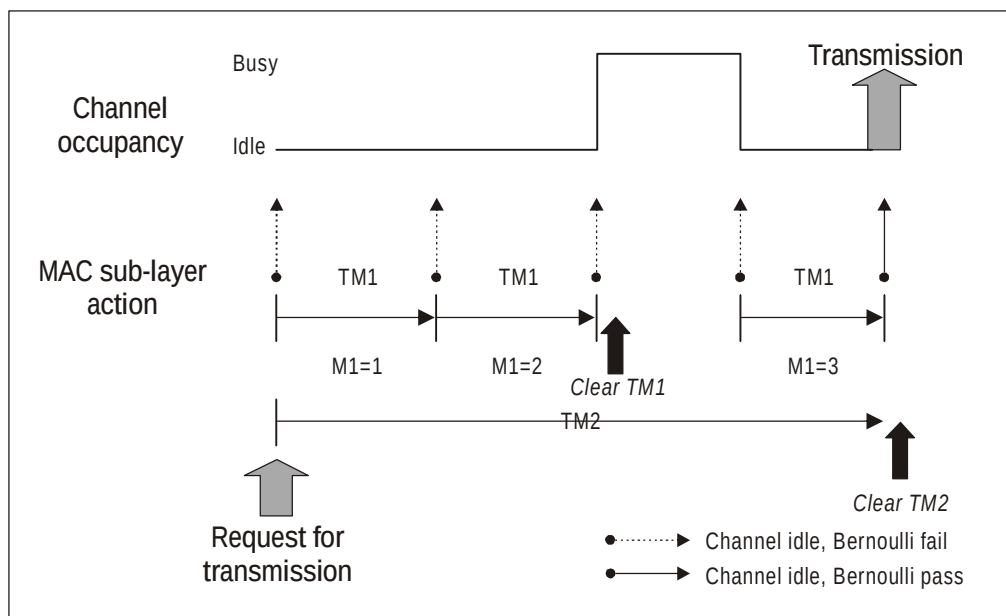


Figure I-3-1. MAC process

3.2.2 Interface to the upper layers

Note.— The primitives defined for the MAC layer are detailed in 3.2.2.1 to 3.2.2.2. Note that primitives to control MAC parameters negotiable via exchange identifications (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 logic link control - Type 1 (LLC_1) sub-layer when the TM2 timer expires indicating a busy channel.

3.2.3 Specification and description (SDL) language

Note.— The SDL description for the MAC sub-layer is in Figure I-1-2.

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

3.3 DATA LINK SUB-LAYER

3.3.1 Architecture

3.3.1.1 The data link entities (DLE), which provide connection-oriented point-to-point links with peer DLEs, exist within the data link sub-layer. 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.

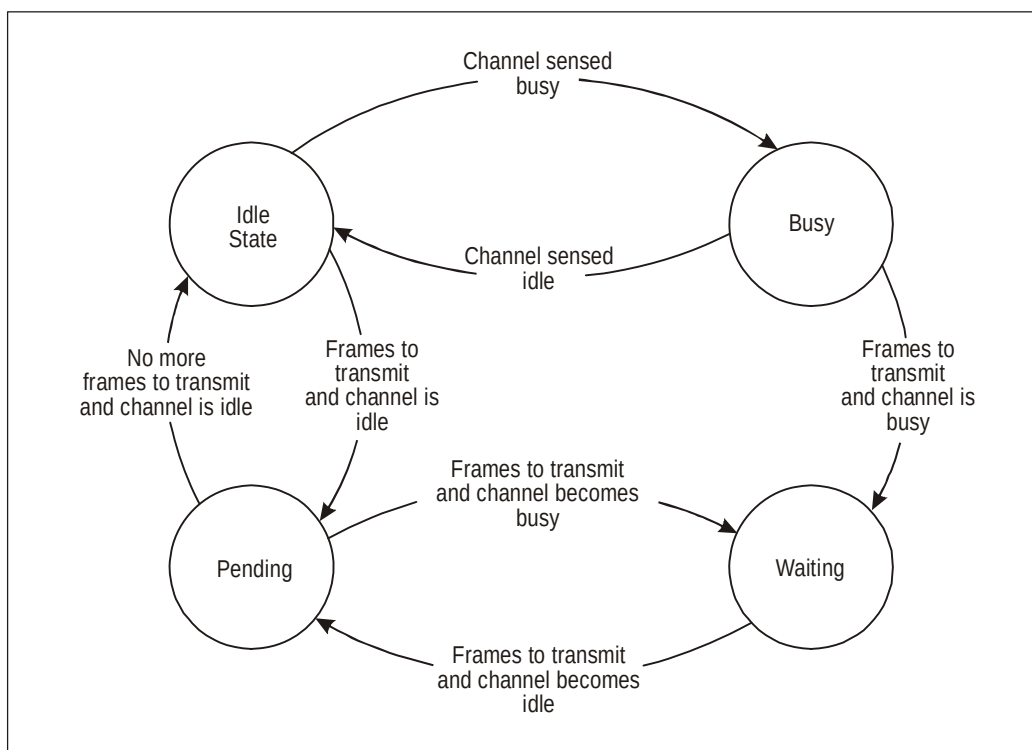


Figure I-3-2. MAC state diagram

3.3.1.2 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 I-3-3 provides an overview of the data link layer with its related sub-layers and entities.

3.3.1.3 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 Mode 2 aircraft having link connections with the ground system. The ground VME will create one LME for every aircraft that is “logged-on” to the VDL Mode 2 ground system and similarly, the airborne VME will create one LME for each ground system with which it is communicating. These peer LMEs will use the information provided by the received XIDs (e.g. lat/long position parameter, airport destination, acceptable alternate ground stations, etc.) and other information sources (e.g. transceiver’s signal quality/strength of received frames) to establish and maintain reliable links between the aircraft and the VDL Mode 2 ground system.

3.3.1.4 In Figure I-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.

3.3.1.5 In a one ground system scenario (i.e. the aircraft is in the coverage area of one VDL Mode 2 data link service provider) the aircraft station will have at most two 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 5.2.3.

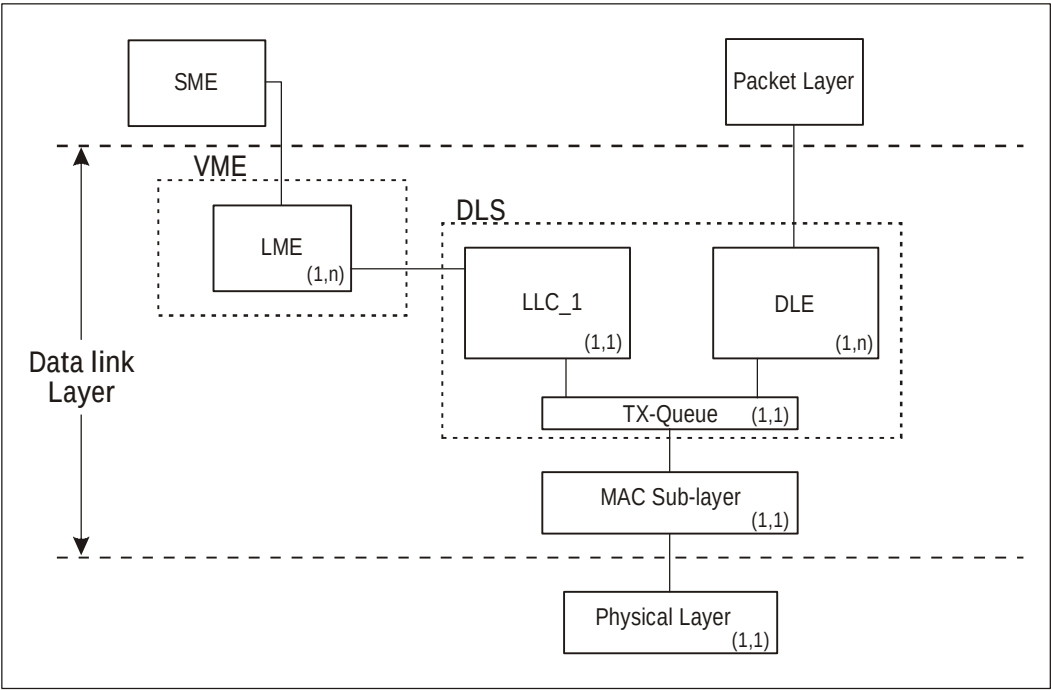


Figure I-3-3. Data link layer overview

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

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

NUMBER OF VMEs	airborne: 1 ground: 1 each (total of 2)
COMMENTS: The airborne and ground systems have only one VME each to manage all VDL links.	
NUMBER OF LMEs	airborne: 2 ground: 1 each (total of 2)

COMMENTS:

Two LMEs exist within the airborne VME and have been created to manage the VDL Mode 2 links #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 DLEs #1 and #2 support the AVLC protocol with ground DLEs #1 and #2. Ground DLE #1 exists within the ground station with which the aircraft has established a link (ground system #1). Similarly, ground DLE #2 exists within the ground station with 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 99th percentile of successfully accessing the channel) and the time to receive an acknowledgement for an unretransmitted frame (i.e. the time for the peer entity to access the channel). This algorithm, based on the algorithm used in the transport control protocol/internetworking protocol (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 Acknowledgement process and transmission queue management. In order to improve the VDL Mode 2 acknowledgement process as well as to minimize the retransmission period which ultimately affects the protocol recovery period, special considerations were given to the frame rejection and T1 timer processes.

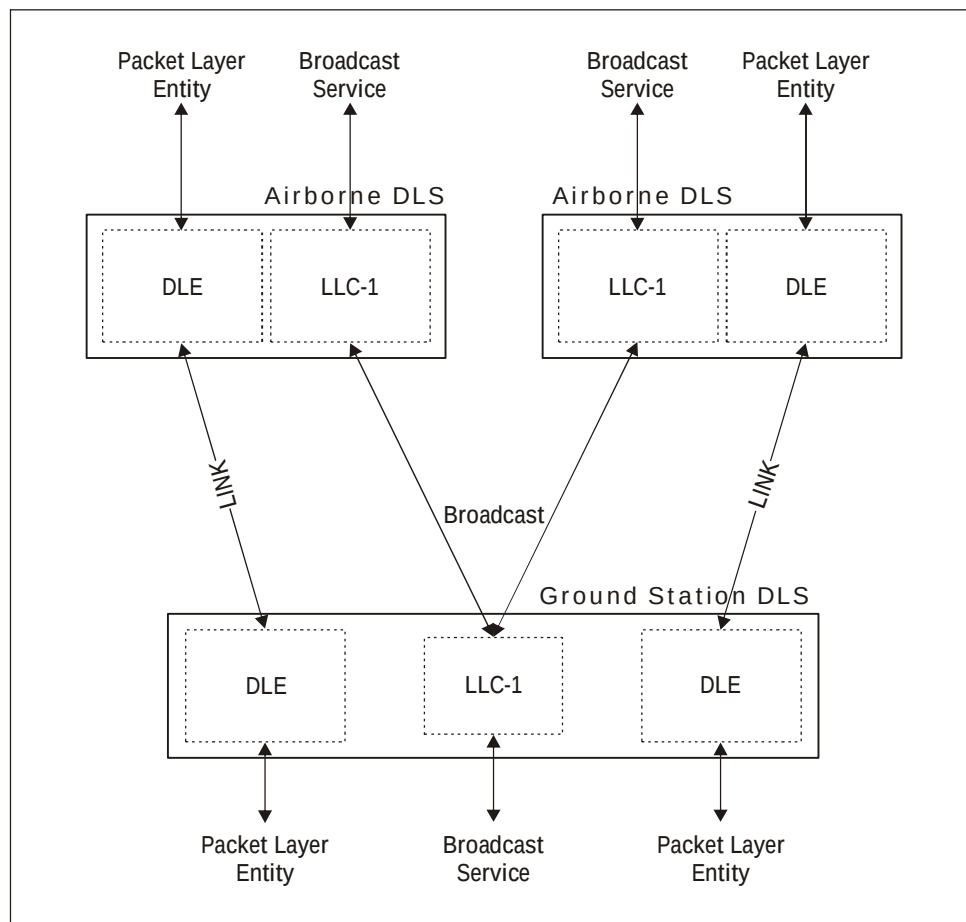


Figure I-3-4. DLS sub-layer architecture

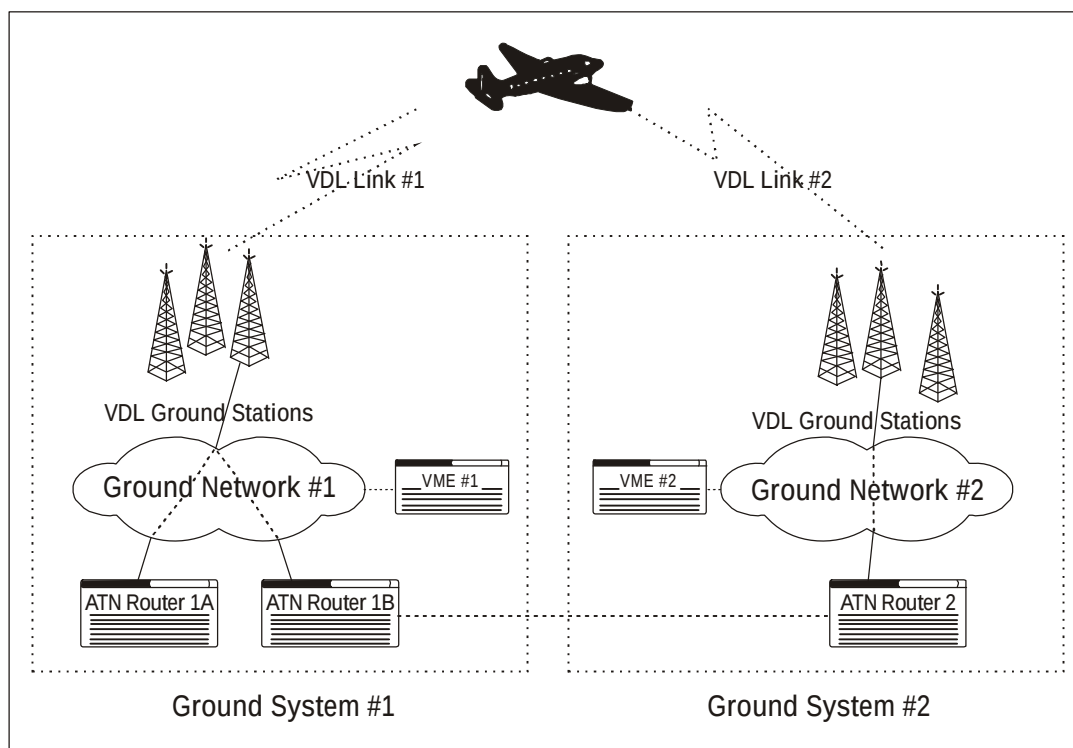


Figure I-3-5. System overview of VME, LME and DLS

3.3.2.3 In VDL Mode 2, 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 from 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. An 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 $T1_{min} + 2TD$ 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 I-3-6 outlines three examples of the SREJ and T1 processes.

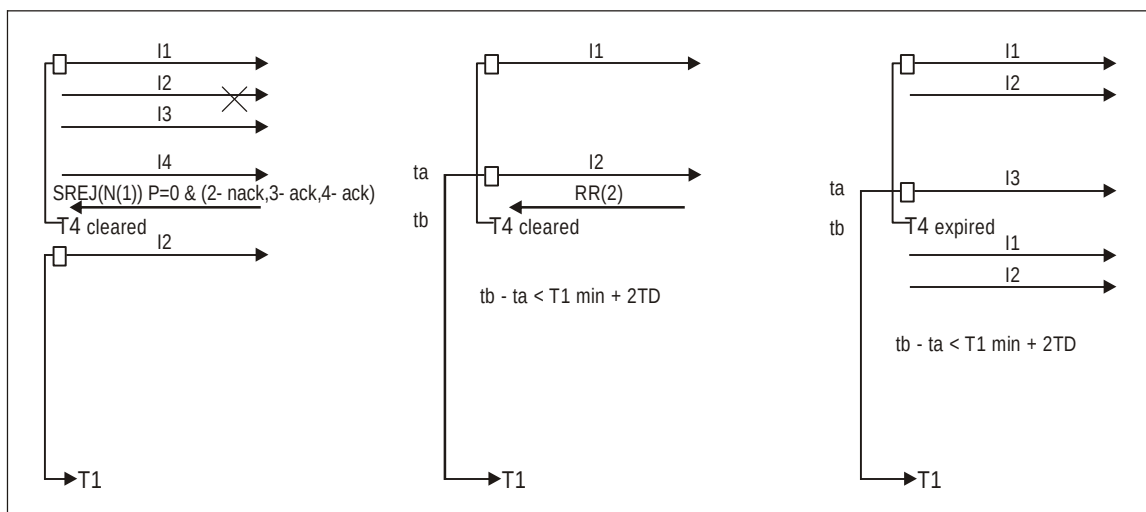


Figure I-3-6. SREJ and T1 flow diagrams

3.3.2.5 **FRMR/UA process.** The frame reject (FRMR) mode frame is always sent as a command (CMD) frame with the poll/final (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 frame with a bad or unknown control field;
- a frame with an invalid size;
- a frame with an invalid acknowledgement number;

- d) a frame received with an invalid command/ response (C/R) bit and/or P/F bit combination (for instance, an unnumbered acknowledgement (UA) frame received as a command, or a response frame with the P/F bit set when a response frame is not expected);
- 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.

3.3.2.5.1 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.

3.3.2.5.2 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 disconnect (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 response 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 a 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 set asynchronous balanced mode (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 corrupt 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 (C/R) status bit.** Normal ISO 4335 procedures use the address field to distinguish command and response frames. However, in a broadcast medium, 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 (DLS) 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 2 (default): $N1 = [11 \text{ (link layer)} + 4 \text{ (packet layer)} + 1 \text{ 024}] \times 8 = 8 \text{ 312}$

Mode 2 (Max): $N1 = [11 \text{ (link layer)} + 4 \text{ (packet layer)} + 2 \text{ 048}] \times 8 = 16 \text{ 504}$

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

3.3.3.1.3.2 T2 Parameter. The VDL Mode 2 station that receives a frame that requires a response has to 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 Mode 2 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 protocol data unit (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 so that the potential for large outages while trying to clear the RNR condition is avoided.

3.3.3.3 **Timers.** Table I-3-2 summarizes the operation of the DLS sub-layer timers.

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 ground station information frame (GSIF) setting new values is received from the ground station with which the aircraft is attempting to establish a link.

Table I-3-2. DLS sub-layer timers

<i>Timer</i>	<i>Started</i>	<i>Cancelled or restarted</i>	<i>Action upon expiration</i>
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 $T1m + 2T1int + 2TD$
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

3.3.4 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 a 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 (Optional (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 a 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 a 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, unicast 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

Note.— The SDL description of the DLS sub-layer is in Figure I-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 sub-layer is outlined in Figure I-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.

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 in the Appendix to Part 1 of this manual.

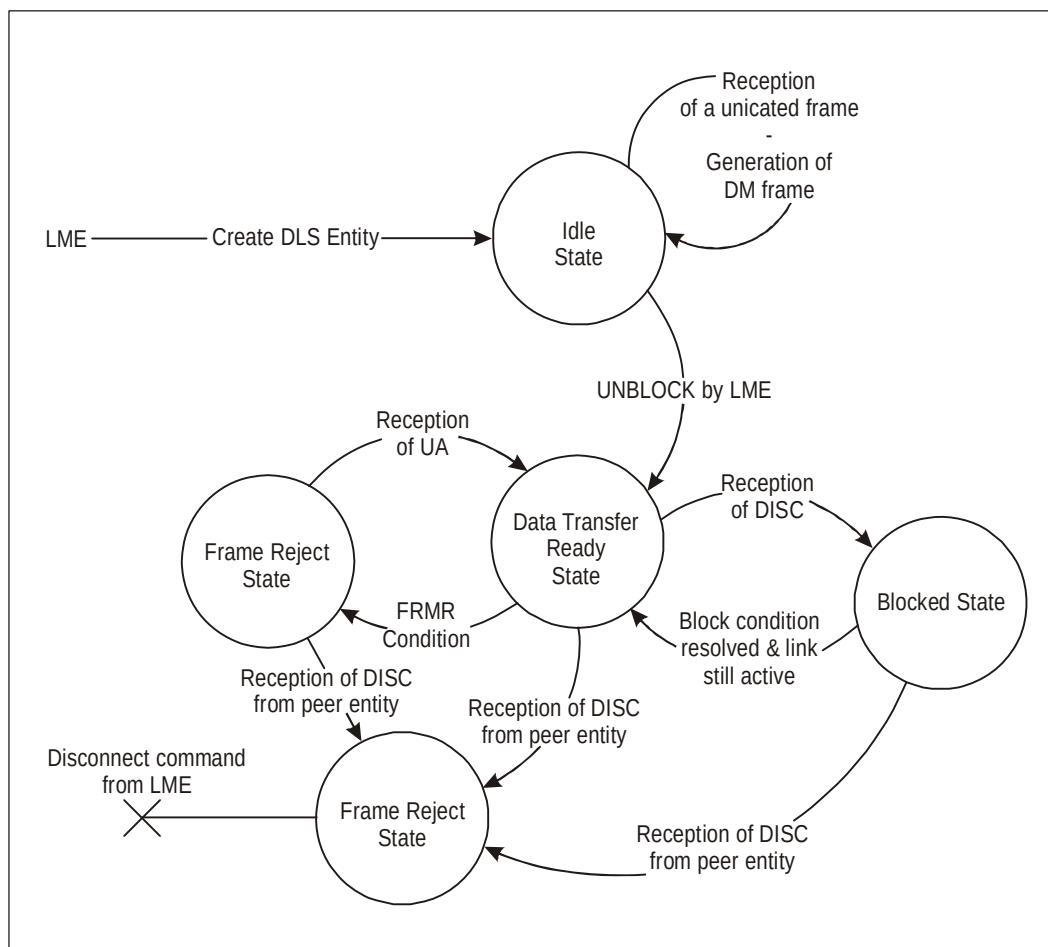


Figure I-3-7. DLS state diagram

3.4 LINK MANAGEMENT ENTITY (LME)

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 either by use of a common signalling channel or by a frequency search function.

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

3.4.1.2 Common signalling channel. The common signalling channel (CSC) (136.975 MHz) is used wherever service providers want to annunciate the VDL availability of CNS services over VHF carriers using the VDL Mode 2 physical and 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 VDL Mode 2 and is in a service area that offers VDL 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 VDL Mode 2 or is not in a service area that offers VDL 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 that 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 Mode 2 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 within 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. The ground TG2 timer, however, 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 subnetwork dependent convergence function (SNDCF) or the intermediate system-system management entity (IS-SME) of the ATN router network entity titles (NETs) information received and the link ID for the new link. The SNDCF will indicate this link ID in all CALL REQUEST primitives that 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 I-3-3 summarizes the timers in the LME sub-layer.

Table I-3-3. LME 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 are listed in Tables II-5-47 a), b) and c) in Part II, Detailed Technical Specifications. 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.

Note.— When a VDL handoff takes place between ground stations connected to different air-ground routers, the aircraft system is recommended to use the new air-ground router. However, both Routes may have equal merit and the IDRP protocol, as currently specified by ATN standards, cannot be expected to select the most appropriate route.

3.4.2.1.2 **Ground station information frames.** Ground stations will periodically transmit ground station information frames broadcasting certain information for the aircraft LMEs to use. (The GSIFs are broadcast in a randomized window so that two transmitters hidden from each other will not synchronize and their signals 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 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. It may also identify other available ground stations. The aircraft LME stores this information to be used when trying to contact the stations during ground station changes. This allows the LME to retune 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 overall 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 retune to a different frequency and initiate a handoff on the new frequency. The replacement ground station parameter will be included to inform the aircraft of which ground station to attempt to contact. Alternately, the Frequency Support List parameter may be used to manage multiple frequencies.

Note.— In order to properly implement make-before-break across two frequencies, the aircraft will need two VDL radios. With only one VDL radio, the system will operate with a break-before-make paradigm. The system will silently disconnect the link before retuning to the new frequency.

3.4.2.1.3.4 Replacement ground station. The replacement ground station parameter can be used without the autotune parameter when the ground stations 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.